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GRIZZLY BEAR HABITAT ANALYSIS

SECTION III

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GRIZZLY BEAR HABITAT ANALYSIS

Section III

LANDSAT-1 MULTISPECTRAL IMAGERY AND COMPUTER ANALYSIS OF GRIZZLY BEAR HABITAT

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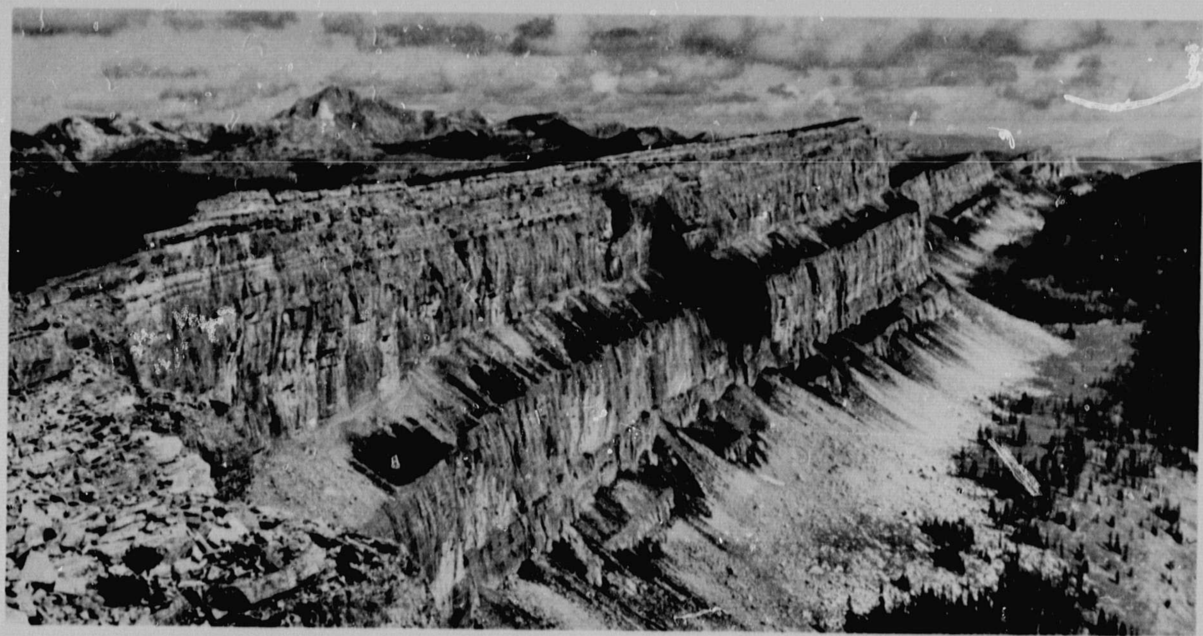
1980

FRONTISPIECE

Three areas were intensively studied to determine the feasibility of using multispectral imagery to map vegetation with computer assistance. Top photo shows characteristic alpine terrain in the primary Scapegoat area; middle photo illustrates typical alpine-subalpine terrain of the secondary Slategoat study site; and lower photo shows temperate zone terrain in the secondary Danaher area.



DEDICATION

This Section is dedicated to Dr. Melville Bell Grozvenor and Melvin M. Payne of the National Geographic Society. Their faith and support made it possible.

ABSTRACT

Multispectral imagery and computer analysis were employed to develop and perfect a system for mapping vegetation of extensive wilderness areas and relating this to grizzly bear habitat requirements.

Using the vegetation ground map and data presented in Section I, broad vegetation classes were distinguished according to their spectral reflectance values established from LANDSAT-1 images of the land/vegetation associations and interpreted through the General Electric interactive multispectral image analysis system. Results of the computer modeling were then refined and (following each of 3 seasons of field testing and vegetation sampling) integrated into first-, second-, and third-generation computer maps with summary statistic readouts. The maps were field tested for accuracy. Computer extrapolations of signature data to unmapped areas of the wilderness ecosystem were also field checked.

The primary area was computer mapped with an overall accuracy of 89%. Using a procedure that accommodated ecotone pixels, the overall numerical expression of accuracy increased to 93%.

Extrapolating data from the primary Scapegoat area to the two secondary areas gave an average extrapolation accuracy for Slategoat and Danaher of 91% and 85% respectively.

Thirteen vegetation complexes were computer delineated to construct the third-generation (final) map of Scapegoat. The vegetation of each complex was described in quantitative terms. The same was done for the secondary study areas, Slategoat and Danaher. The thirteen complexes separated by spectral signatures and/or signature polygons were: Alpine Meadow, Vegetated Rock, Bare Rock I (lichens), Bare Rock II (lichens), Xeric Pinus Albicaulis Forest, Mesic Abies Lasiocarpa/Pinus Albicaulis Forest, Subalpine Parkland, Equisetum Seepage, Forested SCREE, Xeric Abies Lasiocarpa Pseudotsuga Menziesii Forest, Mixed Coniferous Forest, Temperate Parkland, and Carex-Salix Marsh.

The vegetation complexes were first described by their percentage composition of land units, landtypes, and forest habitat types with respective area percentages. Each vegetation complex was then described in greater detail by quantifying percent cover and percent occurrence of ground vegetation and forest undergrowth species. Finally, specific grizzly bear food plants were rated and ranked and related to the vegetation complexes.

To map vegetation with detail and with accuracy using multispectral imagery and computer assistance, the vegetation

sampling must be done by employing land/vegetation classifications based on ecological principles. The results can then be converted to a computerized classification consistent with spectral values. The greater the botanical detail the greater the value of the resulting eco-spectral classification system.

In geographic areas where multispectral imagery is available but vegetation classifications are not or are incomplete, mapping with LANDSAT imagery will be severly limited until ecological classifications of vegetation are developed.

Computer modeled multispectral imagery mapping of vegetation is essentially the conversion of an ecological classification to an eco-spectral classification. The value of the eco-spectral classification is that, within certain ecological limits, it can be computer-extrapolated for relatively large geographic areas minimizing mapping time and costs and maximizing resource information.

Structured, digitized computer compatible data used in conjunction with multispectral imagery constitutes a remarkably versatile and efficient system for planning and managing wilderness resources.

NOTE TO READER

This section is directed to the scientific reader. However, to make the contents more readily available to the lay reader, detailed legends accompany most of the 52 illustrations and figures. The legends are a brief synopsis of the text. A general but comprehensive understanding of the contents of Section III can be obtained by reading the abstract followed by a sequential reading of the figure legends.

ACKNOWLEDGEMENTS

The three separate sections of this study were supported and co-sponsored by grants and funding from the National Geographic Society, National Aeronautics and Space Administration, General Electric Corporation, U.S. Forest Service, Office of Biological Services of the U.S. Fish and Wildlife Service, the Montana Cooperative Wildlife Research Unit, Wildlife Management Institute, Montana Department of Fish and Game, and the Wildlife-Wildlands Institute of the University of Montana Foundation. Funding by the National Geographic Society was especially valuable since it represented nearly 50 percent of our financial support and extended through all years of the study.

The authors of the three sections wish to thank the numerous individuals who provided help in the field. We extend special thanks to Karen Haynam, John W. Craighead, Derek Craighead, Peter Husby, Christopher Servheen, Richard Brown, and Steve Ford. We also appreciate the professional advice and the assistance provided by Robert Pfister, Richard Ringleb, and Bernard Kovalchik in habitat typing the subalpine forest types. Peter Stickney and Klaus Lockschewitz aided in the identification of the flora. Arnold Elser provided logistical field support. Laura Plute and Maggie Morth typed tables and manuscripts. Donald Comstock, Engineer, U.S. Forest Service, and his staff deserve

special credit for assisting in all aspects of the photographic work and for providing photogrammetric expertise that greatly facilitated our efforts. Thanks are extended to Bill Quinn and Steve Vance for the use of a microdensitometer and calmagraphic digitizer. We are indebted to Ned Buchman and Christopher Peterson, IMAGE 100 systems operators at General Electric who supervised the computer programming and contributed in many ways to the success of the study. Charles Croteau, Howard Heydt of General Electric, provided technical assistance and reviewed portions of the manuscripts. Earl Schaler donated his professional advice and provided computer time. Charles Bohn (NASA) provided digital tapes and computer maps and expedited work that required coordination between Goddard Space Flight Center and the General Electric Company. John Schneeburger and members of the National Geographic photographic laboratory assisted in numerous ways. John Mitchell, Pacific University, reviewed most of the manuscript and offered valuable suggestions.

Our acknowledgements would not be complete without expressing gratitude to Donald Ozmun, Charles Pihl, William Gallagher, Loren Kreck, and Juanita Daly. Their generous personal contributions enabled us to maintain continuity of effort when federal funding was austere. The final stages of this project were largely dependent on their financial support and on a generous gift from the Richard K. Mellon Foundation.

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INTRODUCTION

My major objective in this third section of the Scapegoat study was to distinguish broad land/vegetation classes by the spectral reflectance values received from LANDSAT-1 images. The LANDSAT-1 images were interpreted through the General Electric interactive multispectral image analysis system (Image 100). I refined and integrated the results with the ground map developed in Section I of this study.

The ground map and data in Section I described the vegetation composition of the Scapegoat Study Area and permitted an evaluation and delineation of grizzly bear habitat. However, ground mapping is a laborious, time consuming process not adaptable to rapid, large-scale mapping of ecosystems. At the outset I believed that by applying satellite multispectral imagery and computer analysis techniques an accurate ecologically-based vegetation ground map could be produced. I believed this could be accomplished at the series-landtype association level (A "series" is a group of vegetation systems within the "region" category that have a common dominant climatic

species (Peterken 1970), while a "landtype association" is composed of landtypes grouped according to their association with each other (Corliss and Pfister 1973). Vegetation/land system classifications in the lower categories were defined in Section I.) and if smaller units of series and of landtype associations (Fig. 1) could be botanically described from ground mapping and vegetation sampling, the resulting maps, with area statistics, would have obvious advantages in delineating critical habitat for the grizzly bear and other wildlife species.

To ensure that computer-processed spectral data agreed with ground truth botanical data and so resulted in an accurate map, I established the following criteria:

1. Spectral classes had to correspond with ecological ground truth data;

2. Spectral classes had to correspond with quantitative vegetation descriptions based on ecological principles;

3. Spectral classes had to correspond with vegetation descriptions for geographic areas of extrapolation outside the primary study area.

Meeting these criteria would show that spectral reflectance values could be consistently equated with specific ecologically-defined biotic resources. It would prove that vegetation resources can be mapped with ecologic consis-

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Fig. 1 Relationship between vegetation/land systems ranked by the "Ecoclass Method" of Daubenmire (1952), Peterken (1970), and Corliss and Pfister (1973) and the computer-designated vegetation/land spectral classes.

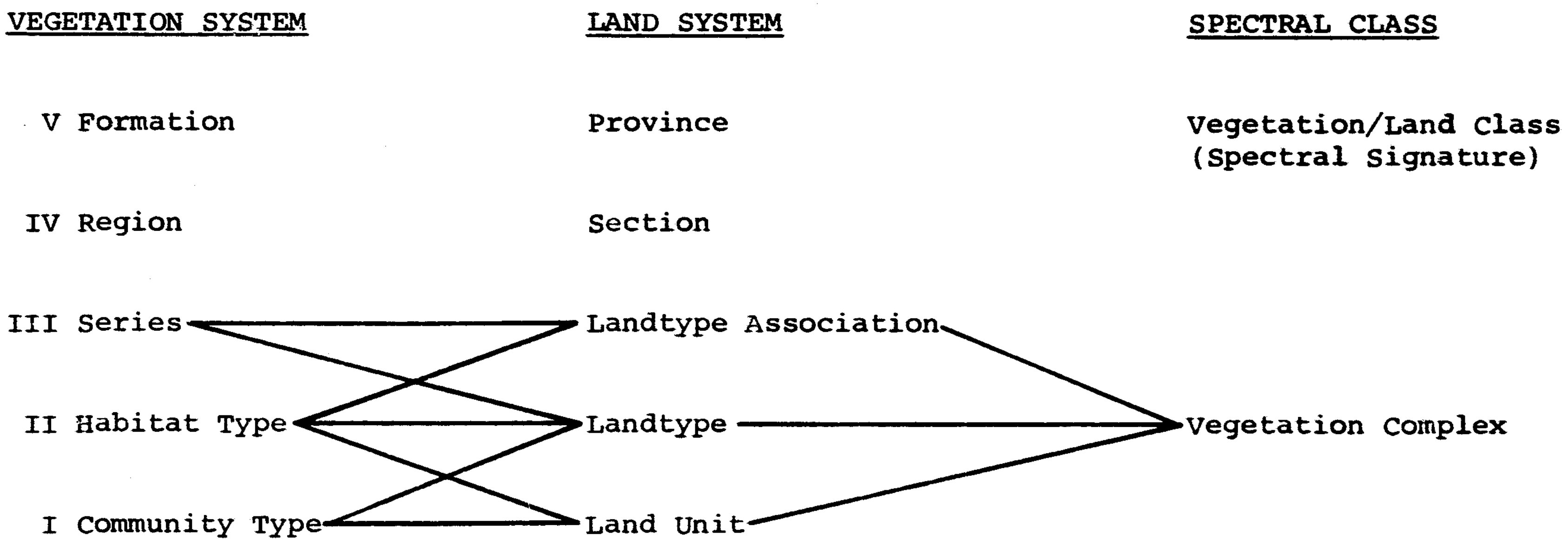
VEGETATION SYSTEM
LAND SYSTEM
SPECTRAL CLASS
V Formation
Province
Vegetation/Land Class
(Spectral Signature)
IV Region
Section
III Series
Landtype Association
II Habitat Type
Landtype
Vegetation Complex
I Community Type
Land Unit

Fig. 2 Frame 1036-17571, 28 Aug 1972, converted from computer compatable digital tape to a LANDSAT photographic scene at a scale of 1 to 3,000,000. The frame shows the location of the primary study area (1) and the two secondary study areas (2 and 3). The 115-x-115 mile (185-x-185km) frame contains 6 million 1.12-acre (.45ha) picture elements or pixels. The three study areas (1, 2, and 3) lying within the Bob Marshall-Scapegoat Wilderness areas are composed of 44,253, 76,962, and 21,156 pixels, respectively, or a total of 159,455 acres (64,531ha).

The major landmarks moving clockwise from the upper left portion of the frame are: Flathead Lake, Swan Lake, Bob Marshall Wilderness, Blackfoot and Clark's Fork River valleys (lower right), a portion of the Selway Bitterroot Wilderness (lower left) and the Flathead Valley and Flathead River, upper left. Missoula, the major city within the frame, lies at the conjunction of the Blackfoot, Clark's Fork and Bitterroot rivers (lower center).

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tency, using multispectral imagery.

To test extrapolation of data from the primary area (Scapegoat), I chose two secondary study areas in the Bob Marshall Wilderness, Slategoat and Danaher. Both secondary areas ecologically resemble all or part of the primary area. The Danaher, named for the Danaher River, has extensive areas in the temperate zone; the Slategoat extensive alpine and subalpine areas. The 41.7 square mile ($108.0km^2$) Danaher area lies adjacent to the west border of the Scapegoat area (Fig. 2). Less rugged than Scapegoat, its elevations range from 4900 feet (1494m) in the valleys to 7700 feet (2347m) at Pinnacle Peak. Most of the area lies in the temperate zone between 5000 to 7000 feet (1524-2134m). Tracts of grass-shrubland interspersed with coniferous forests on both argillite and limestone strata characterize Danaher. Two major rivers drain the area: the South Fork of the Flathead flowing north and the North Fork of the Blackfoot flowing south.

The Slategoat Study Area (named for its 8878 foot (2706m) peak) is 27 miles (43.5km) north of the primary study area in the Flathead and Lewis and Clark National Forests (Fig. 2) Precipitous limestone and argillite cliffs, sharp mountain peaks, and extensive alpine meadows and park-

lands characterize the topography of the 134.7 square mile ($348.9km^2$) area (Figs. 3 and 4). A vertical escarpment, the "Chinese Wall", extends along most of the western border, Fig. 5. Moose, Burnt, Red Butte, Pine and Rock Creeks, originating in the western portion of the area, flow below the wall east into the South Fork of the Sun River. The eastern portion of the study area is drained by Glen, Bear, Goat, and Prairie Creeks flowing into the Sun River. Slategoat Mountain is the highest peak, but many other peaks approach this altitude. Large stands of timber, severely burned in the early 1900s, are now in fire successional stages (Fig. 6).

The ultimate objective of this study was to use the data from the spectral signatures of the primary area and extrapolate an accurate vegetation map of the secondary areas. If this was possible, then MSS imagery could be used to map extensive tracts of wilderness in a matter of hours at relatively little cost. The maps and supporting statistics could serve many uses. They could be used to interpret forest ecology, determine habitat requirements for wildlife species, and facilitate land management decisions. Animal numbers and density could be estimated for wildlife populations by correlating

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Fig. 3 Slategoat Study Area. Landform diversity characterized this secondary study area. Landform similarity of Slategoat with the primary Scapegoat area can be observed by comparing Figs. 3-6 with Figs. 1b, 1c, 1d and 2 of Section I.

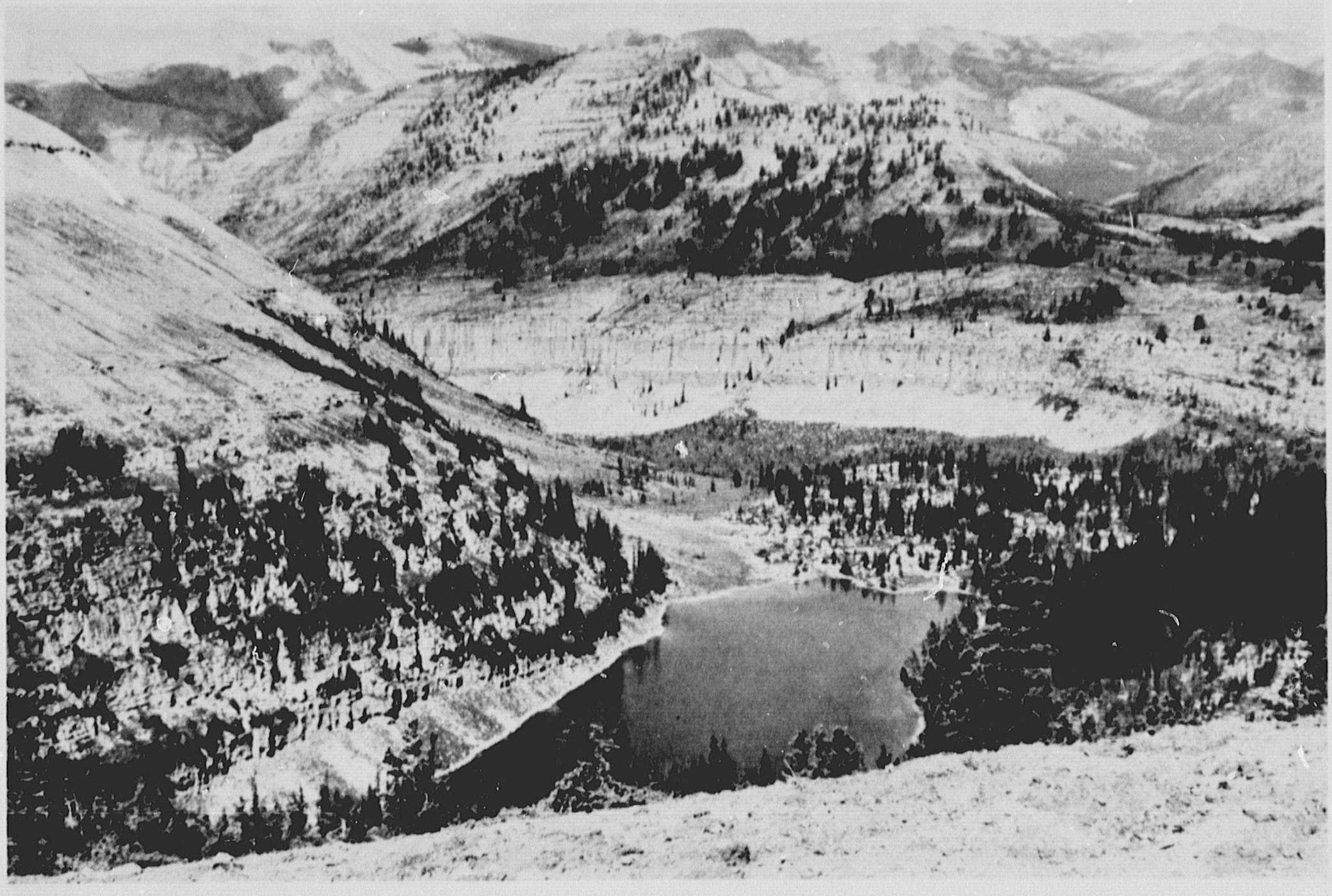

Fig. 4 Upper photograph-Gently sloping alpine meadows often abruptly ended in precipitous limestone cliffs within the Slategoat Study Area.

Lower photograph-Landform diversity in the alpine zone of Slategoat presented a challenge to computer mapping by signature extrapolation from the Scapegoat area.

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Fig. 5 The "Chinese Wall", a vertical limestone escarpment, paralleled most of the western boundary of the Slategoat Study Area.

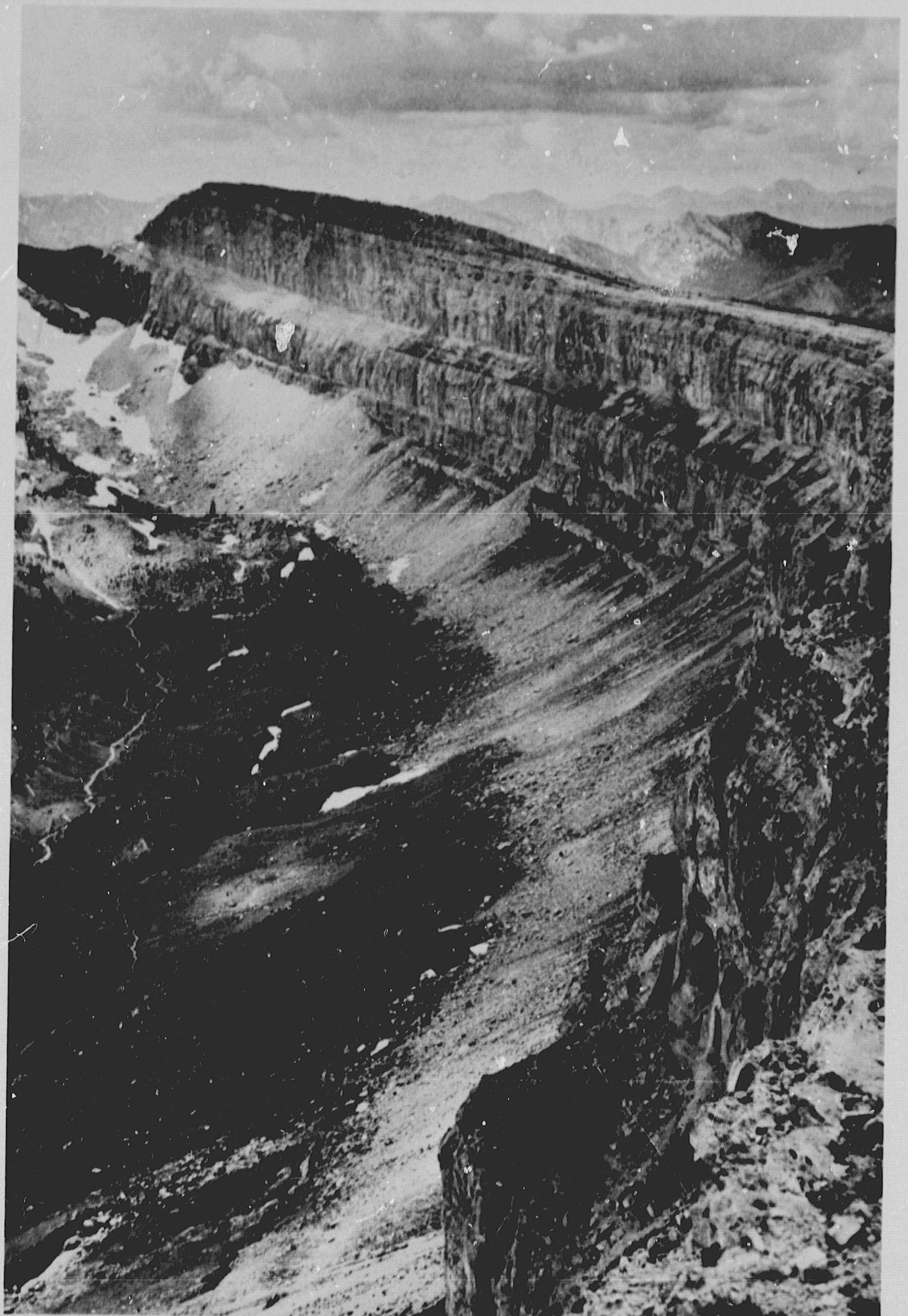

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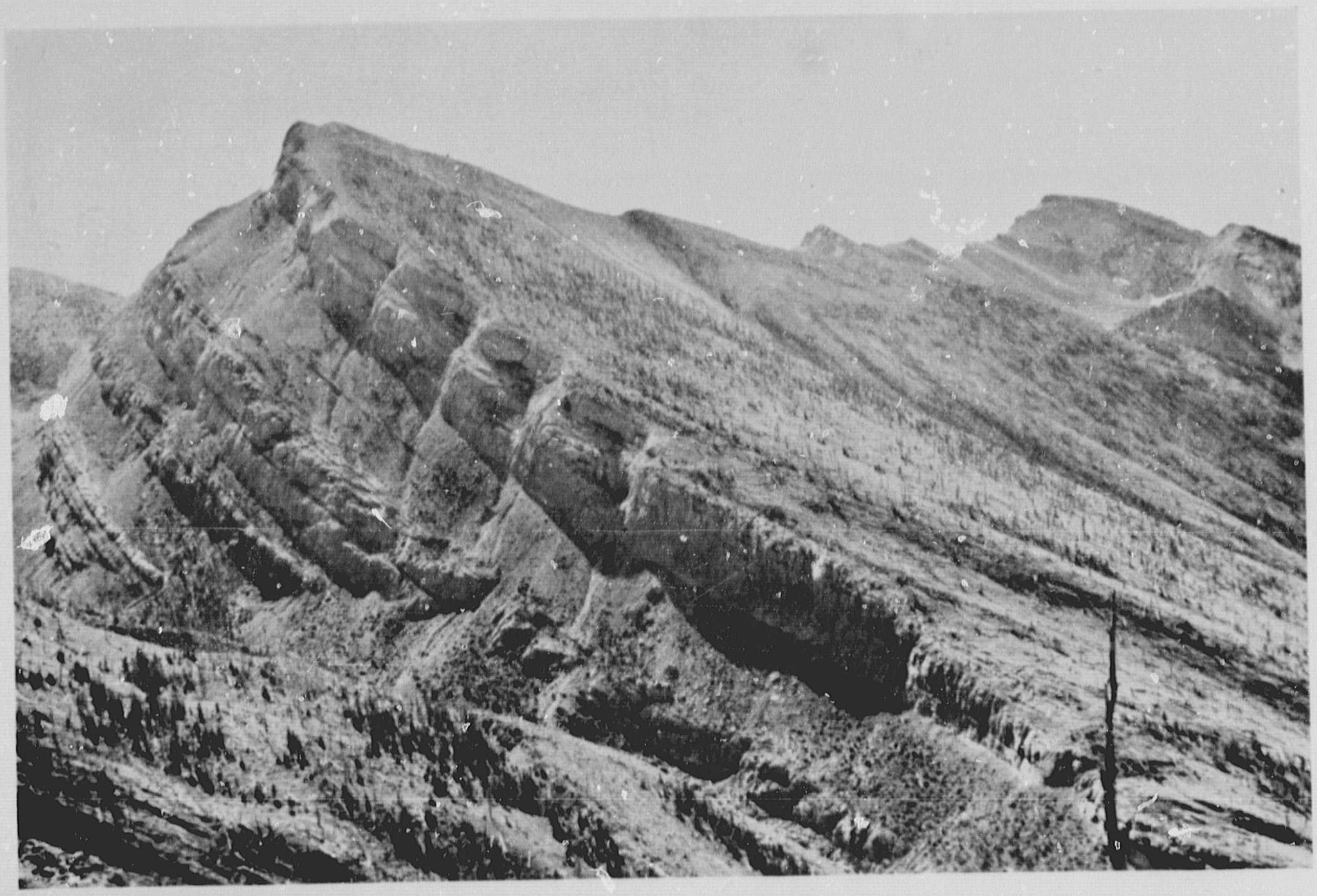
Fig. 6 Seral Forest Stages (Burns) were a result of fires in the early 1900s. Prior to burning, the areas supported mature forests of subalpine fir and whitebark pine.



census data with spectrally designated vegetation complexes and relating this in turn to quantitative measurements of the food supply.

The computer-constructed habitat maps, with their statistical readouts for large geographic areas, could be rapidly and continuously updated. The results could greatly enhance wilderness resource management.

METHODS

LANDSAT Technology

Multispectral imaging from orbiting satellites has a demonstrated potential for surveying and mapping inaccessible and spacious wilderness areas that comprise grizzly bear habitat (Varney et al. 1974 and Craighead et al. 1976). I have combined conventional on-the-ground data gathering techniques with satellite remote sensing and computer image processing. A brief description of this process follows.

The Earth Resources Technology Satellite (LANDSAT-1), launched 23 July 1972, orbits the earth at altitudes varying from 560 to 590 miles (900 to 950km). It makes 14 polar orbits per day, completing an orbit every 103 minutes. During each north-south orbit the satellite

gathers a continuous series of images of the earth's surface with the multispectral scanner system (MSS). It scans adjacent areas on successive daily orbits, moving from east to west, covering the entire surface of the earth every 18 days. Thus, the satellite updates any particular area at 18-day intervals. LANDSAT-2 was launched 22 January 1975. Its orbit was spaced relative to the orbit of LANDSAT-1 to provide routine 9-day photographic coverage of the earth.

The multispectral scanner continuously sweeps an image sensor back and forth across the area beneath the satellite's path. The scanner splits radiation from the earth's surface into four spectral bands measured by detectors for each: viz., green (0.5 - 0.6 μm), red, photographic infrared (0.6 - 0.7 μm) and near infrared (0.8 - 1.1 μm). The intensity in each band is continuously recorded, converted to digital form, and stored on magnetic tape for periodic transmission to a ground receiving station. The continuous data strip received on the ground is converted into a series of frames, each covering an area 115 x 115 miles (185 x 185km). A north-south overlap of about 10% occurs on successive frames taken in each orbit at mid-latitudes. An east-west overlap

of about 40% occurs on frames taken on successive days from adjacent orbits. About 1350 framed images are received daily from the satellite, recorded on film and in digital form on computer-compatible tapes.

A single frame or scene contains four images, one from each spectral band. An image from any one of the bands contains over six million picture elements or "pixels". Each pixel carries the brightness level of a portion of the earth's surface measuring about 260 feet (79m) in diameter and having an area of 1.12 acres (0.45ha). The entire LANDSAT frame, or any portion of it, can be viewed and analyzed.

Because alpine vegetation reaches peak growth in late August, I chose LANDSAT-1 data frame 1036-17571, 28 August 1972. This scene was cloud free over the entire study area (Fig. 2); with a subsatellite point of 47.30° N-113.80° W and a sun angle of 46.0° elevation, azimuth 143.0°.

Procedures of Computer-assisted Data Analysis and Mapping

I used the General Electric interactive multispectral image analysis system (Image 100) to process the LANDSAT images from the available digital computer-com-

patible tapes. The system measures and classifies reflective brightness values. The major elements of the system are: an auxiliary image scanner unit, an image analyzer console with CRT screen, a refresh and store module, and a minicomputer process controller.

The level of energy reflectance registered in each of the four LANDSAT spectra provides the necessary information to identify and characterize a surface area. Like objects or areas in a LANDSAT scene generally have similar properties in the four spectral bands. Computer analysis, given a proven reflectance range for a surface area, provides a rapid, accurate means of inventorying, classifying, and measuring classes of vegetation (Anderson et al. 1975; Driscol and Francis 1975; and Hoffer et al. 1975). Variations in spectral response caused by mountain topography and distinguishing spectrally similar areas that are actually different vegetation or cover types pose problems discussed in detail later.

The system console displays images recorded by LANDSAT-1. The user can select "training sites" - small areas of the scene to be minutely analyzed in terms of constituent pixels. Once a particular characteristic of

a training site, e.g., meadowland, is identified and recorded as a range of spectral reflectance, that range is termed a "signature". On command from the operator the computer scans the rest of the scene pixel by pixel. All areas corresponding to the signature extracted from the training area are displayed in a single assigned color termed the "theme". At any time during the analytical process the user can obtain spectral histograms, histogram lists, cluster displays, or other statistical reports for each training area. These statistics are displayed on the printer/plotter in real time giving the user the opportunity to modify and improve the signature. The user refines and modifies the signature using the ground truth data, repeating the process until he achieves a classification of vegetation that correlates closely with ground maps and sample sites. This process is called "thresholding". The signature results, stored on binary-theme channels and pseudo-CCTs, can be recalled to form a thematic map on the screen and can be printed as black-and-white hard copy or as color prints (dicomed).

Correlation with Ground Truth Data

I selected training sites for extracting signatures using ground truth data obtained by on-site field inspec-

tion, vegetation sampling, and vegetation/landform mapping. Overhead color photographs of the study area from a mission flown by U.S. Forest Service personnel in mid-August, 1975, and color oblique photographs obtained from Forest Service regional files were extremely useful in the interpretation of field data.

Generalized ground truth information gathered in the field during the summer of 1972 gave me computer training sites for bare rock, alpine meadows, subalpine parks, and northwest and southeast forest exposures. A first generation computer-assisted thematic map was developed from these training sites. The map was enlarged to 4-inches to-the-mile(1:15840) on transparent acetate and superimposed over 4-inches-to-the-mile, black and white orthophotos (1:15840) enlarged from a Forest Service high altitude photo (scale 1:63360) having contour lines overlayed from U.S.G.S. maps of the Scapegoat area.

During the summer of 1975 the above combination of maps was used in the field to verify computer classifications and to detect misclassified and unclassified vegetation. The large-scale map combination allowed the ground crews to orient themselves with topographic and vegetational features of the landscape and, in turn, to precisely locate

vegetation sample plots and test sites. The maps, used also to record forest habitat types and ecological land units, served additional functions both as ground truth records and for comparison with computer-thematic maps.

The study area was divided into alpine, subalpine, and temperate zones according to elevation. The forest habitat types were mapped by one field team, while the alpine and subalpine grass-shrubland vegetation was mapped by another. The resulting conventional vegetation map (refer to Figure 37 and Section I) provided accurate ground truth reference points for refinement of the first generation thematic map.

Landforms typifying ecological land units (ELUs) in the alpine zone and ecological landtypes (ELTs) in the subalpine and temperate zones were classified and mapped in the field using large-scale aerial photographs. I analyzed vegetation characterizing the ELUs and ELTs, while that characterizing the forest habitat types (HTs) was interpreted according to Pfister et al. (1977).

Ecological land units, having similar landforms, tended to support similar vegetation associations. Ocular estimates and vegetation sampling indicated a gradient in vegetation density from bare rock to alpine tundra.

Interpretation of color photographs suggested that this gradient represented a series of ELUs (Table 1). To roughly test this hypothesis I employed Spatial Data Systems' micro-densitometer with color monitor and digital density readout, an instrument capable of measuring apparent brightness (photographic density levels or "gray levels") with a resolution of 1:256 (0.4%).

Correlation with Micro-Densitometer Data

Each ecological land unit of interest was measured on color photographs using the micro-densitometer. The analysis of a series of samples representative of each of the 12 ecological units (Table 2) provided quantitative gray level readings for each. All vegetation was masked on the aerial photographs except that in the sample sites (Fig. 7). A reflectance sensor scanned vegetation on the sample sites and displayed a false color image which was compared with ground truth data and adjusted to eliminate all density readings except those for vegetation. Ocular estimates of percent vegetation cover from ground sampling correlated reasonably with percent vegetation cover determined from micro-densitometer analyses (Table 3). This showed that differences in percent vegetation between ELUs could be recorded in gray level values and, thus,

Table 1: Acreage and Ocular Estimates of Percent Vegetative Cover in Alpine Ecological Land Units.

Ecological Designation	Total Acreage of ELUs	Samples		Percent Vegetative Cover	
		No.	Acreage	Range	Mean
Alpine Meadow	336.3	39	9.9	75-100	86.7
Vegetated Talus	328.5	4	1.0	60-80	70.0
Alpine Meadow Krummholz (trees excluded)	359.5	22	5.6	20-100	62.5
Slab-Rock Krummholz	295.1	8	2.0	30-95	70.0
Slab-Rock Steps	493.1	21	5.3	15-100	54.3
Glacial Cirque Basins	1148.8	32	8.1	5-95	42.2
Mountain Massif	550.0	11	2.8	30-100	50.0
Semi-vegetated Talus	676.6	10	2.5	20-35	27.0
Fellfield	392.7	11	2.8	15-90	37.3
Bare Talus	1276.7	33	8.4	5-10	4.8
Parent Rock	1047.2	-	-	-	-
Snowfield Sink	86.6	-	-	-	-
and Permanent Snowfields	67.9	-	-	-	-

Table 2: Acreages and Micro-densitometer Gray Level Readings for Alpine Ecological Land Units.

Ecological Designation	Total Acreage of ELUs	Sampling Sites No.	Sampling Sites Acreage	Sampling Sites % ELU	Gray Level (% Vegetation) Range	Gray Level (% Vegetation) Mean	Vegetative Rating
Alpine Meadow	336.3	7	74.1	22.0	99-70	88.0	2
Alpine Meadow Krummholz	359.5	3	80.2	22.3	90-75	82.0	3
Slab-Rock Krummholz	295.1	3	104.3	35.3	87-53	71.0	4
Slab-Rock Steps	493.1	7	98.1	19.9	84-44	66.0	5
Glacial Cirque Basin	1148.8	7	321.6	28.0	66-37	50.0	6
Mountain Massif	550.0	5	143.1	26.0	59-17	41.8	7
Fellfield	392.7	6	53.5	13.6	48-14	32.0	9
Vegetated Talus	328.5	7	33.6	10.2	95-88	91.0	1
Semi-Vegetated Talus	676.6	6	56.0	8.3	53-31	37.0	8
Bare Talus	1276.7	11	90.0	7.0	10-0	4.7	10
Parent Rock	1047.2	8	189.1	18.1	7-0.5	3.7	11
Snowfield Sink	86.6	3	9.0	10.4	6-3	4.7	10
and Permanent Snowfield	67.9	6	12.4	18.3	0.5-0.5	0.5	12
Total*	7059.0	79	1265.0	17.9	-	-	-

* Total for alpine zone is 7746.0 acres (12.1 square miles (31.3km^2)), including Island Krummholz (201.1 acres) and intrusions of subalpine forest types (485.9 acres).

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Fig. 7 Locations of sample micro-densitometer sites on Scapegoat Plateau. A mylar overlay of these sites was positioned over the MSS imagery as an aid in obtaining unique signatures for rock and vegetation classes in the alpine zone. A similar procedure was used to develop signatures for subalpine and temperate zone rock and vegetation classes.

5G
8F
4F
4G
2B
3B
3A
3C
5C
2A
7F
4A
5B
1A
1B
1C
5D
6A
6B
6D
6C
6E
7G
7B
9A
1E
7D
8R

Table 3: Comparison of Percent Vegetative Cover for Ecological Land Units derived from ground sampling and from micro-densitometer gray-level readings.

Ecological Land Unit	Percent Vegetative Cover: Ground Sampling Range	Ground Sampling Mean	Micro-densitometer Range	Micro-densitometer Mean
Alpine Meadow	75-100	86.7	70-99	88.0
Vegetated Talus	60-80	70.0	88-95	91.0
Alpine Meadow Krummholz (trees excluded)	20-100	62.5	75-90	82.0
Slab-Rock Krummholz	30-95	70.0	53-87	71.0
Slab-Rock Steps	15-100	54.3	44-84	66.0
Glacial Cirque Basins	5-95	42.2	37-66	50.0
Mountain Massif	30-100	50.0	17-59	41.8
Semi-Vegetated Talus	20-35	27.0	31-53	37.0
Fellfield	15-90	37.3	14-48	32.0
Bare Talus	5-10	4.8	0-10	4.7
Parent Rock	-	-	-	-
Snowfield Sink	-	-	-	-
and Permanent Snowfields	-	-	-	-

that alpine landforms tended to support classifiable vegetation which could be mapped in terms of differences in spectral reflectance.

Integration of Data into Thematic Maps

Construction of a second generation thematic map required defining broad vegetation classes that could be computer-mapped according to unique signatures or a combination of signature data and altitudinal zoning. I grouped the habitat types, ELUs, and ELTs ground-mapped in Section I using the Image 100 with the objective of defining the vegetation/land systems at the series-landtype association level. These were evaluated in terms of spectral values (vegetation classes) and/or altitude and consolidated into "vegetation complexes" (Fig. 1).

I used the altitudinal zones defined in Section I, viz., alpine (9000-7600 feet) (2742-2316m), subalpine (7600-7000 feet) (2316-2134m) and temperate (below 7000 feet) (213[illegible]). The vegetation complex could represent any one of a number of vegetation system/land system combinations. For example, the Alpine Meadow Complex is a community-type land unit, while the Abies Lasiocarpa/

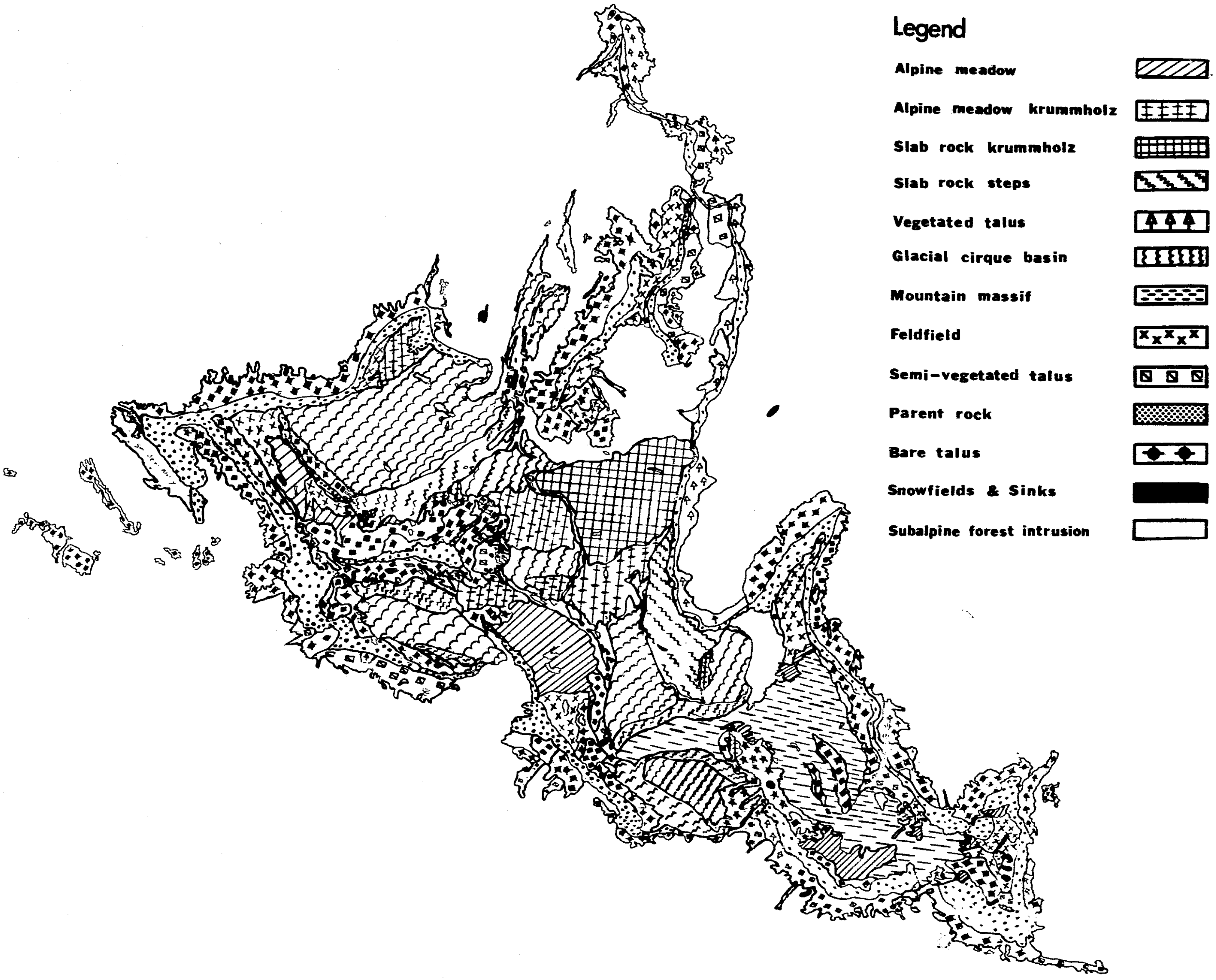
Pseudotsuga Menziesii Forest Complex is a series-landtype association. The vegetation complexes representing unique spectral reflectance values within defined altitudinal zones provided both the ecological and spectral foundation for the computer thematic map.

Spectral Classification

A portion of LANDSAT-1 scene 1036-17571 (28 August 72) that includes the Scapegoat Plateau and adjacent areas was enlarged on the system color display screen (Fig. 8). The area displayed about 78 square miles ($202km^2$). The system operator performed training and classification on 2 of the 4 spectral bands (green and near infrared (bands 5 and 7). A scaled mylar overlay (Fig. 9) of the vegetation/land systems used as training areas for defining the vegetation classes was positioned on the input stage for scanning. Similarly, a second mylar overlay (Fig. 3) of the sample micro-densitometer sites was positioned for scanning. Using the overlays, specific land areas (ELUs) were recognized as indicated in Figs. 7 and 9. Signatures were then developed from clearly established training sites. Procedures were similar for ELTs and forest habitat types. This greatly reduced the possibility of introducing

Fig. 8 Digital display of the Scapegoat Plateau and adjacent areas. This shows the imagery as it appeared on the CRT screen enlarged to 3-inches-to-the-mile (1:21120). Training sites were located on the imagery, spectral signatures obtained and a false color assigned to each signature. The thematic map composed of the 6 color-encoded signatures is shown in Fig. 11.

Fig. 9 Mylar overlay of ecological land units that served as training areas in the alpine zone on Scapegoat Plateau. These training areas were printed on mylar and positioned over the MSS imagery for scanning by the Image 100 Computer.


Legend
Alpine meadow
Alpine meadow krummholz
Slab rock krummholz
Slab rock steps
Vegetated talus
Glacial cirque basin
Mountain massif
Feldfield
Semi-vegetated talus
Parent rock
Bare talus
Snowfields & Sinks
Subalpine forest intrusion

signature errors due to imprecise location of training sites.

For a given training area, minimum and maximum reflectance values, in each of the 2 bands, defined the limits of a 3-dimensional spectral parallelepiped. As the displayed image was scanned pixel by pixel, those pixels lying within the spectral bounds of the parallelepiped were identified ("alarmed") on the CRT screen. Spectral signatures for each training site were modified by thresholding the parallelepiped boundaries to increase or decrease the "alarm" area coincident with ground truth data regarding cover or habitat types. This method of obtaining signatures is termed the "supervised approach" and produces a unimodal spectral class for each vegetation grouping. A disadvantage of the supervised approach is that cover types represented by only a few pixels are often lost in clusters of another cover type exhibiting a different spectral value. I solved this problem by combining unique signatures obtained from ecologically similar vegetation to produce a reflective spectral classification or signature that would represent a combination of cover types.

Signature Blocks in Bands 5 and 7

Figure 10 shows 6 signatures as groups of gray levels in bands 5 and 7. For example, values for the Whitebark Pine and for the Douglas-Fir Forest Complexes range from 10 to 16 μm in band 5 and 16 to 33 μm in band 7. Similarly, gray level values for talus slopes in shadow are 19-37 μm in band 5 and 6-13 μm in band 7. Gray level values for each of the 6 signatures can be read from the graphic representation. The 6 signatures represented 6 vegetation/ land classes (distinctive spectral themes). I defined these as rock and vegetation classes on the second generation thematic map (Fig. 11) of the Scapegoat Study Area, as follows:

1. Alpine Meadow and Subalpine and Temperate Parkland
2. Vegetated Rock
3. Largely Limestone (Parent Rock 2)
4. Argillite (Parent Rock)--Talus Slopes (Shadow - Rock 1)
5. Whitebark Pine Forest
6. Mixed Coniferous Forest

Of these classes, three corresponded well with ecologically meaningful groupings of ELUs and were designated vegetation or rock complexes as follows:

1. Vegetated Rock Complex
2. Bare Rock Complex (limestone/parent rock or talus)
3. Bare Rock Complex (argillite/shadowed talus)

Fig. 10 Signature blocks in Bands 5 and 7 used to construct the second generation map of Scapegoat. To obtain the unique signatures, a number of training areas for each theme were located in the field and recorded on orthophoto maps. These training sites were later located on the MSS imagery. The training sites (images) were then displayed and scanned pixel by pixel by the computer to produce a unimodal spectral class for each vegetation or rock grouping. Unique signatures from ecologically similar vegetation were combined to produce the four unique spectral classifications (signatures) shown here. Each represented a combination of cover types and is termed a theme or class.

SECOND GENERATION

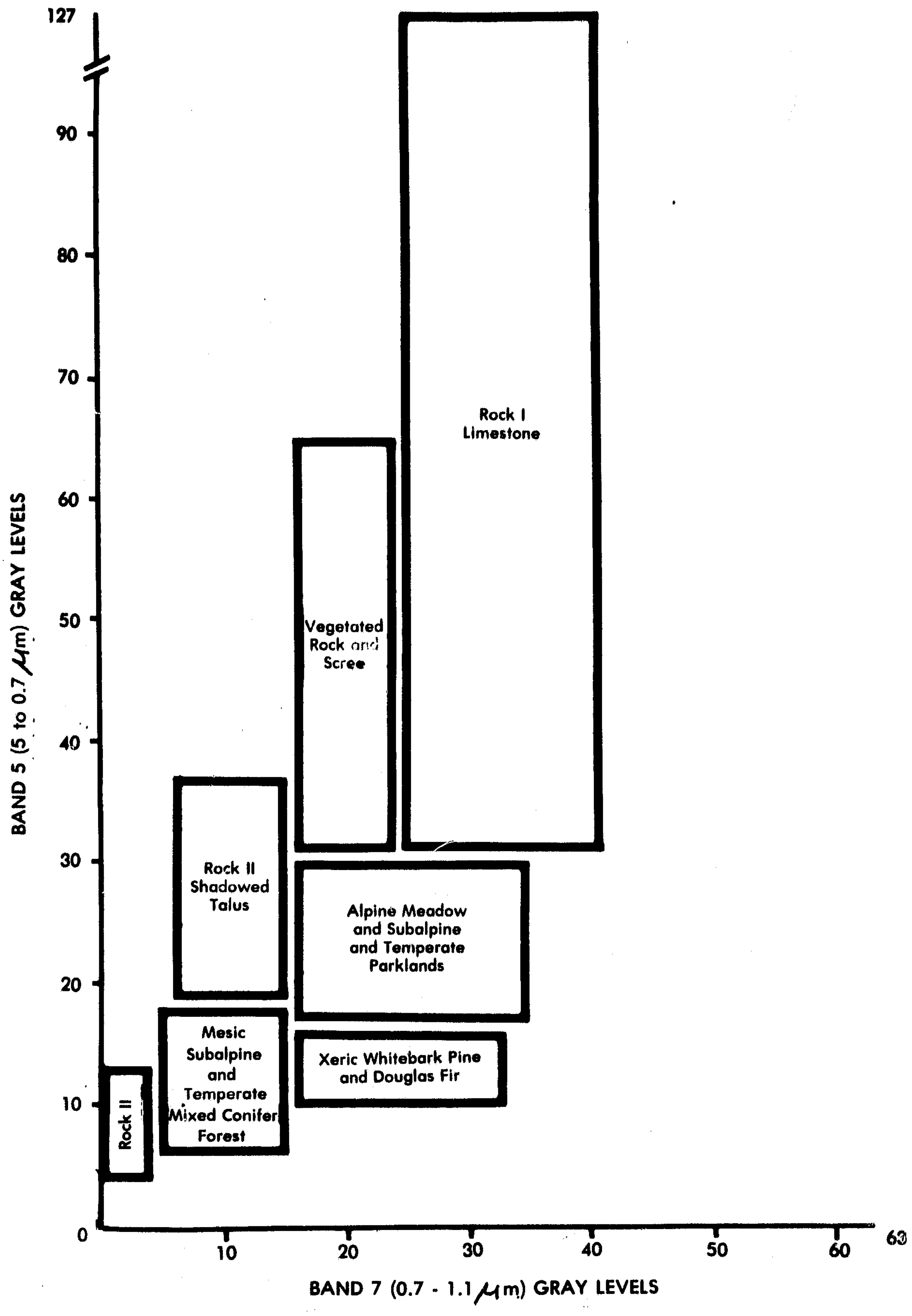
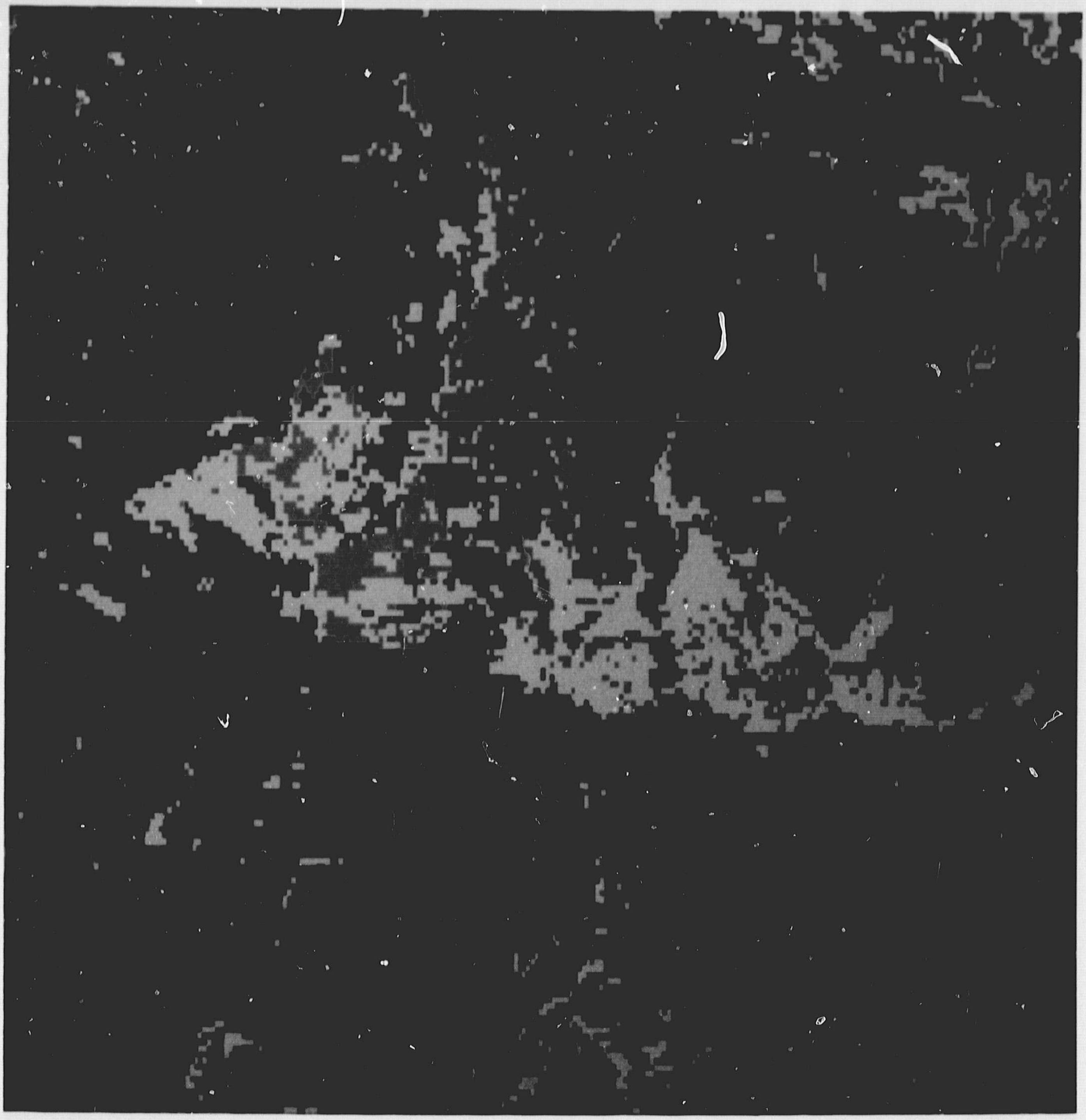


Fig. 11 Display of 6 color-encoded signatures used to construct the second generation map of Scapegoat.

The area embraces 3 climatic zones. At this stage in map construction no signature or summary polygons were employed. The blue theme, representing grass-shrub parkland, was later differentiated into Alpine Meadow and Sub-alpine Parkland Complexes by designating spacial zones (see Fig. 28). Separate encoded colors were assigned each complex. The theme was further sub-divided to form the Temperate Parkland Complex in the third generation map (Fig. 29). Also in the third generation map, the violet theme here representing both the subalpine and the temperate mixed coniferous forests was differentiated by spacial zones into the Mesic Abies Lasiocarpa/ Pinus Albicaulis Forest Complex above 7000 feet (2134m) and the Temperate Mixed Coniferous Forest Complex below that elevation. The green theme here, representing xeric *Pinus albicaulis-Abies lasiocarpa* and *Pseudotsuga menziesii* forests of the subalpine and temperate zones, respectively, was also differentiated above and below the 7000 foot (2134m) contour into 2 complexes; the Xeric Pinus Albicaulis Forest Complex of the suablpine zone and the Xeric Abies Lasiocarpa-Pseudotsuga Menziesii Forest Complex of the temperate zone. Individual color codes were assigned to each vegetation complex differentiated within the spectral signatures by spacial zoning (Fig. 29).



The "talus slope" class, though unique spectrally because of shadowing, was, for practical purposes, included into the Argillite Bare Rock Complex.

Each of three remaining themes was known to include several vegetation/land groupings that could be ecologically, but not spectrally, differentiated. These vegetation groupings were sufficiently distinct (as to community, structure, and composition) that they could be mapped if there was a way to differentiate them. The most obvious differentiating parameter was altitude. I zoned the spectral values by altitude, according to ecologically defined vegetation groupings, representing seven vegetation complexes. These complexes, listed according to the spectral classes within which they were defined, were:

Class I - Alpine Meadow (alpine zone)
Complex 1 - Alpine Meadow Complex

Class I - Parkland (subalpine zone)
Complex 2 - Subalpine Parkland Complex

Class I - Parkland (temperate zone)
Complex 3 - Temperate Parkland Complex

Class II - Whitebark Pine Forest (subalpine zone)
Complex 4 - Xeric Pinus Albicualis Forest Complex

Class II - Whitebark Pine Forest (temperate zone)
Complex 6 - Xeric Abies Lasiocarpa/Pseudotsuga Menziesii Forest Complex

Class III - Mixed Coniferous Forest (subalpine zone)
Complex 5 - Mesic Abies Lasiocarpa/Pinus Albicaulis Forest Complex

Class III - Mixed Coniferous Forest (temperate zone)
Complex 7 - Mixed Coniferous Forest Complex

Therefore, while the signatures for the second generation thematic map spectrally delineated 4 vegetation classes, a more definitive classification required the use of elevation zoning to delineate additional vegetation complexes from 3 of the 4 spectral classes. For example, the alpine meadow produced a signature indistinguishable from that of the subalpine and temperate parklands. Similarily, the mesic forests of the subalpine zone composed of *Abies lasiocarpa* and *Pinus albicaulis* were not spectrally divisible from the mixed coniferous forest of the temperate zone. Likewise, the xeric subalpine forests composed of *Pinus albicaulis* and *Abies lasiocarpa* were spectrally identical to the xeric temperate forests composed of *Abies lasiocarpa* and *Pseudotsuga menziesii*. However, altitude zoning (employing the technique of constructing signature and summary polygons) permitted the delineation of 4 vegetation complexes that could not be separated by spectral values alone. The method of employing both signatures and signature poly-

gons resulted in 10 complexes that could be mapped from LANDSAT imagery with computer assistance.

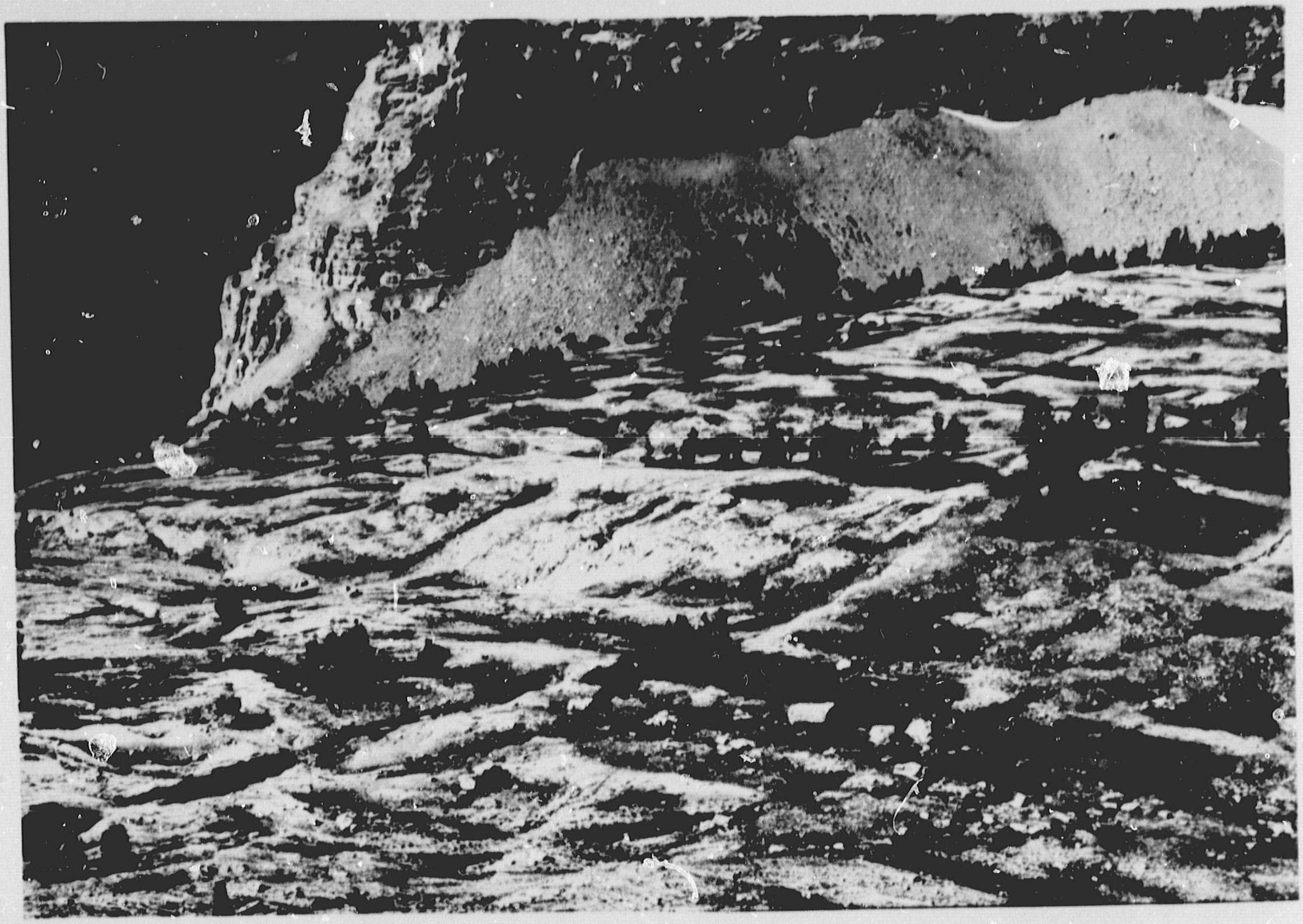
Signature and Summary Polygons

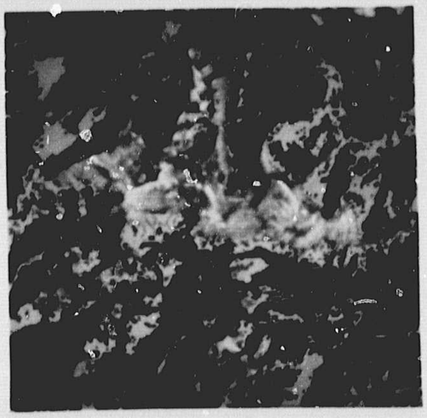
To construct the second generation map, I differentiated the Alpine Meadow Complex from the Subalpine Parkland Complex by the designation of spacial zones in the form of polygons with each polygon defined by a series of vertex coordinates. No other altitudinally defined spacial zones were employed for the second generation map (Fig. 28).

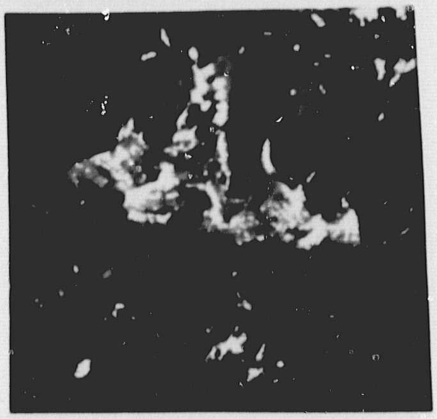
The classified pixels were replaced with color-encoded ones, thus visually separating the Alpine Meadow Complex from the Subalpine Parkland Complex. The final second generation map (Fig. 28) was developed from 6 signatures and 2 "signature" polygons, one for the Alpine Meadow Complex and one for the Subalpine Parkland Complex. The result was 8 complexes, each displayed in false color. Figure 12 illustrates the appearance of 3 of the 8 complexes as displayed on the LANDSAT imagery and pictures the landscape in which all 3 of the complexes occurred.

I recognized that with additional ground truth data, the open-canopied xeric coniferous forests could be separated into a Xeric Pinus Albicaulis Forest Complex and

Fig. 12 Three vegetation complexes superimposed upon the LANDSAT imagery, and a photograph of the landscape in which all three Complexes occur. Complexes displayed are, left to right, Xeric Pinus Albicaulis, Vegetated Rock, and Limestone Rock. See Fig. 10 for signature data.





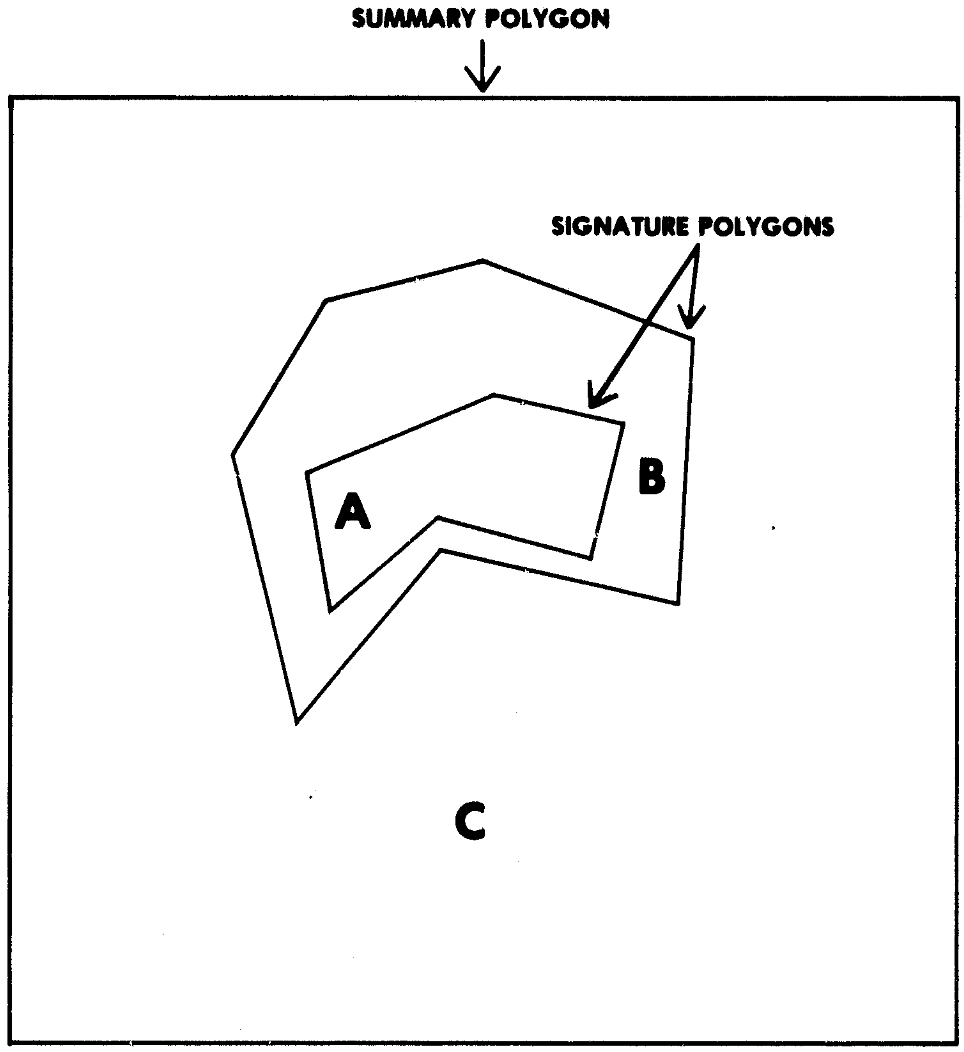


a Xeric Abies Lasiocarpa/Pseudotsuga Menziesii Forest Complex. Similarly, signature polygons could spacially zone both the grass-shrublands of the subalpine and temperate zones into Temperate and Subalpine Parkland Complexes, and the closed-canopied coniferous forests into a Mesic Abies Lasiocarpa/Pinus Albicaulis Forest Complex and a Mixed Coniferous Forest Complex.

Accordingly, this was accomplished for the third generation map with a bulk processor on the Image 100. The MSS data were processed by designated spacial zones based on altitudinal contours within the scene. This allowed classification of themes exhibiting different vegetation, but similar spectral characteristics in different altitudinal or geographical areas. For example, the Alpine Meadow Complex was geographically separated from the Subalpine Parkland Complex by a "signature" polygon A, at 7600 feet (2316m) and above. The Subalpine Parkland Complex lay between the 7600 foot and the 7000 foot (2316 and 2134m) contours. It was, in turn, separated from the Temperate Parkland Complex by "signature" polygon B at 7000 feet (2134m) and below (Fig. 13). The same procedure was used in separating the vegetationally different but spectrally similar forest complexes.

Fig. 13 Summary polygon of the Scapegoat Study Area. Polygon A is a signature polygon, designating the spatial-zone-spectral signature for the Alpine Meadow Complex. Polygon B, exclusive of polygon A, designates the spatial zone for the Subalpine Parkland Complex. Area C, exclusive of A and B, designates the spatial-zone-spectral signature for the Temperate Parkland Complex.

The summary polygon is the spatial zone (Scapegoat Study Area) for which area statistics were computed using MSS imagery and signature data. It equals the summation of signature polygons A, B, and C within the LANDSAT scene.



KEY

A — 7600' and above
B — 7600' - 7000'
C — 7000' and below

The polygon procedure was:

1. An arbitrary x-y coordinate system was assigned to a map by overlaying gridded mylar.

2. Three spacial zones were defined as signature polygons.

3. All areas above 7600 feet (2316m) were defined with a series of straight lines which best approximated the curved topographic lines. This formed Polygon A, Fig. 13. Similarly, all areas between 7600 and 7000 feet (2316 and 2134m) were defined as well as areas at 7000 feet (2134m) and below. This formed Polygons B and C.

4. The x-y coordinates were extracted for each of the intersections or vertices of the straight lines.

5. Three ground control points were defined by locating three well-defined points on the map and extracting the x-y coordinate for each. Next, the same three ground control points were found in LANDSAT scene coordinates, scan line and element number.

6. The x-y coordinates for the vertices and the ground control points, were processed by the prebulk processor which transformed all the vertices from the arbitrary coordinate system to the LANDSAT coordinate system.

7. Signatures, to be applied to each polygon, were specified, as well as which polygons required summary statistics, as input to the Bulk Processor. Output from the Bulk Processor was classified data on magnetic tape where classified pixels replaced original data; and summary statistics for each signature within the summary polygon. This provided a table of area summaries giving area measurements for each unique category (signature) within each of the spacial zones.

The summary polygon was the entire Scapegoat Study

Area. The signature polygons represented 3 spacial zones or areas defining the alpine, subalpine and temperate climatic zones within the summary polygon (Fig. 13). Each unique category was one of 13 vegetation complexes that the Image 100 computer integrated into the third generation thematic map of the Scapegoat area. The result was a more refined thematic map with each color theme representing a rock or a vegetation complex botanically described.

Parameters Affecting Forest and Grassland Spectral Classifications

Though categorization of the complexes was possible using a combination of spectral reflectance and altitudinal zoning (spacial zones), computer-modeling of the study area clearly did not proceed on the basis of classifying particular species within the forest habitat types and parkland complexes. Distribution of themes on the second generation thematic map indicated that the computer interpretation of spectral reflectance was related to broad ecological situations - the individual and combined effects of several variables. Probable sources of spectral variation included aspect and its partial derivations, moisture and canopy cover density.

Aspect and Elevation

I examined the importance of aspect and elevation in spectral reflectance by superimposing a ¼ inch (6.35mm) grid overlay on a 3-inches-to-the-mile (1:21120) thematic contour map of the Scapegoat Study Area. Aspect and elevation, within the two forest themes and the parkland theme, were determined by locating the midpoint of each of 2328 grid squares. Aspect and elevation were then recorded within each grid square as indicated by the contours on the thematic map at grid square mid-point. The habitat types and ecological landforms were similarly recorded. The Xeric Pinus Albicaulis Forest Complex was subjected to additional testing. The complex was ground-checked above 7000 feet (2134m) on 123 randomly located 0.20 acre (.08ha) sample plots to relate moisture and aspect with spectral data.

Canopy Cover

I found cover density (canopy cover) as much a function of aspect and, thereby, moisture, as it was of species forming the canopy. Differentiation of the forest themes from the parkland theme was not a computer interpretation of forested versus non-forested canopy cover.

Rather, computer interpretation was one of gradation in canopy cover from light to heavy.

Canopy cover density, as it related to both thematic assignment and aspect, was analyzed by locating and defining sample grid sites according to theme and aspect on a contoured thematic map. Canopy cover was then evaluated as (heavy, >50%, moderate, 35-50%, light, <35%) for the identical site on color, aerial oblique photographs. The two sets of data were compared and expressed as percent occurrence of heavy, moderate, and light canopy for 8 aspects within the major forest complexes. The evaluation of computer interpretation of aspect and canopy, as these related to computer classification, was then compared with vegetation ground truth data.

Grid Overlay Sampling Procedure

I used a grid sampling technique to obtain data from the computer thematic maps. The data helped me evaluate and interpret spectral reflectance values in relation to aspect, altitude and cover density. The method yielded random data that could be related to the color-coded themes and then to the specific parameters of

altitude, aspect, and vegetation types, all of which influenced gray level readings. The materials required were a 3-inches-to-the-mile (1:21120) color-coded thematic map (dicomed), a transparent U.S.G.S. contour overlay scaled to the thematic computer map, a vegetation type map, and grid overlays. All overlays were superimposed over the thematic maps for point by point grid tabulations. The grid overlay consisted of 2328 ¼-inch (6.35mm) squares, each square representing 17.8 acres (7.2ha). The grid represented an area of 75 square miles ($194.3km^2$) or 48,000 acres (19,426ha). The number of grid squares employed in sampling varied with the parameters sampled and with the thematic map employed.

Color-coded theme, elevation, aspect and vegetation type (ELU, ELT, or habitat type) were recorded from the map overlays for the midpoint of each grid square. The point by point grid checks were further verified for each parameter by reference to colored aerial oblique photographs and specific site information gathered in the field. I summarized the data by category and converted to percent values.

Testing Accuracy of Computer-Modeled Thematic Maps

I found it difficult to devise a completely satis-

factory accuracy test using ground test sites because ecotone gradients existed within the test sites of the spectral classes they represented. An ecotonal gradient is a subtle intergredation between different classes or themes of vegetation that can be recognized in the field and on colored aerial photographs. Within a given class they could be assigned to either of two intergrading spectral classes and be correct. Accuracy was therefore tested with and without ecotone inclusions. Both methods are described and results for both methods are presented.

Primary Study Area

The second generation thematic map of the primary area (Scapegoat) was checked for accuracy by comparing the computer-assigned vegetation classes (spectral themes) with ground truth data obtained on 336 test sites of 5.1 acres (2.1ha) (4.6 pixels) each (Figs. 14 and 15). A pixel represents 1.12 acres (.45ha) measuring 259 x 188 feet (78.9m x 57.3m). The sites, as plotted on an orthophoto of the Scapegoat Study Area (Fig. 16), were identified, and a correct or incorrect classification recorded by employing a 3-inches-to-the-mile (1:21120) transparency of the orthophoto superimposed over the 3-inches-to-the-mile (1:21120) color-coded thematic map. The test sites

Fig. 14 Establishing field test sites in the alpine zone of Slategoat.

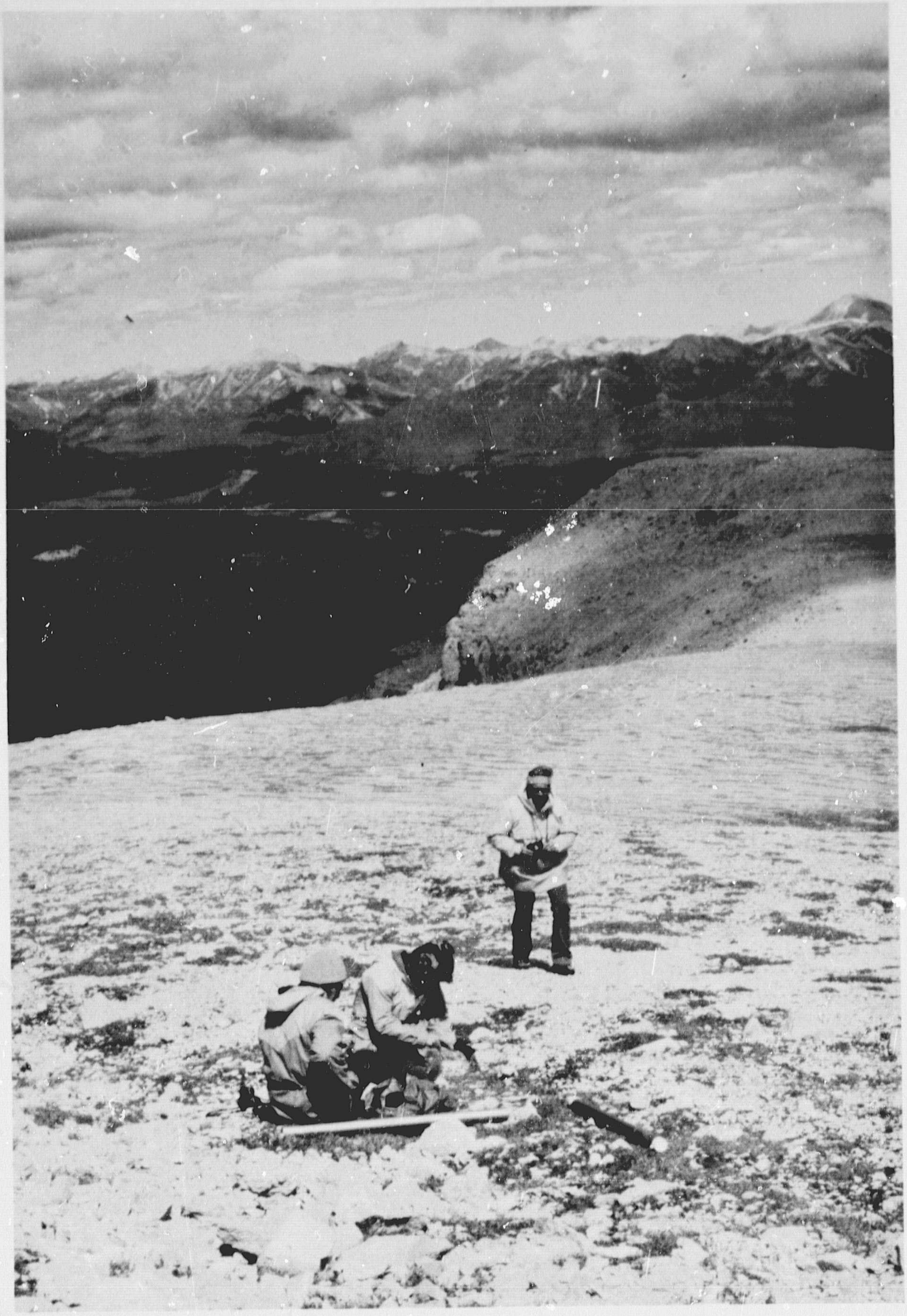
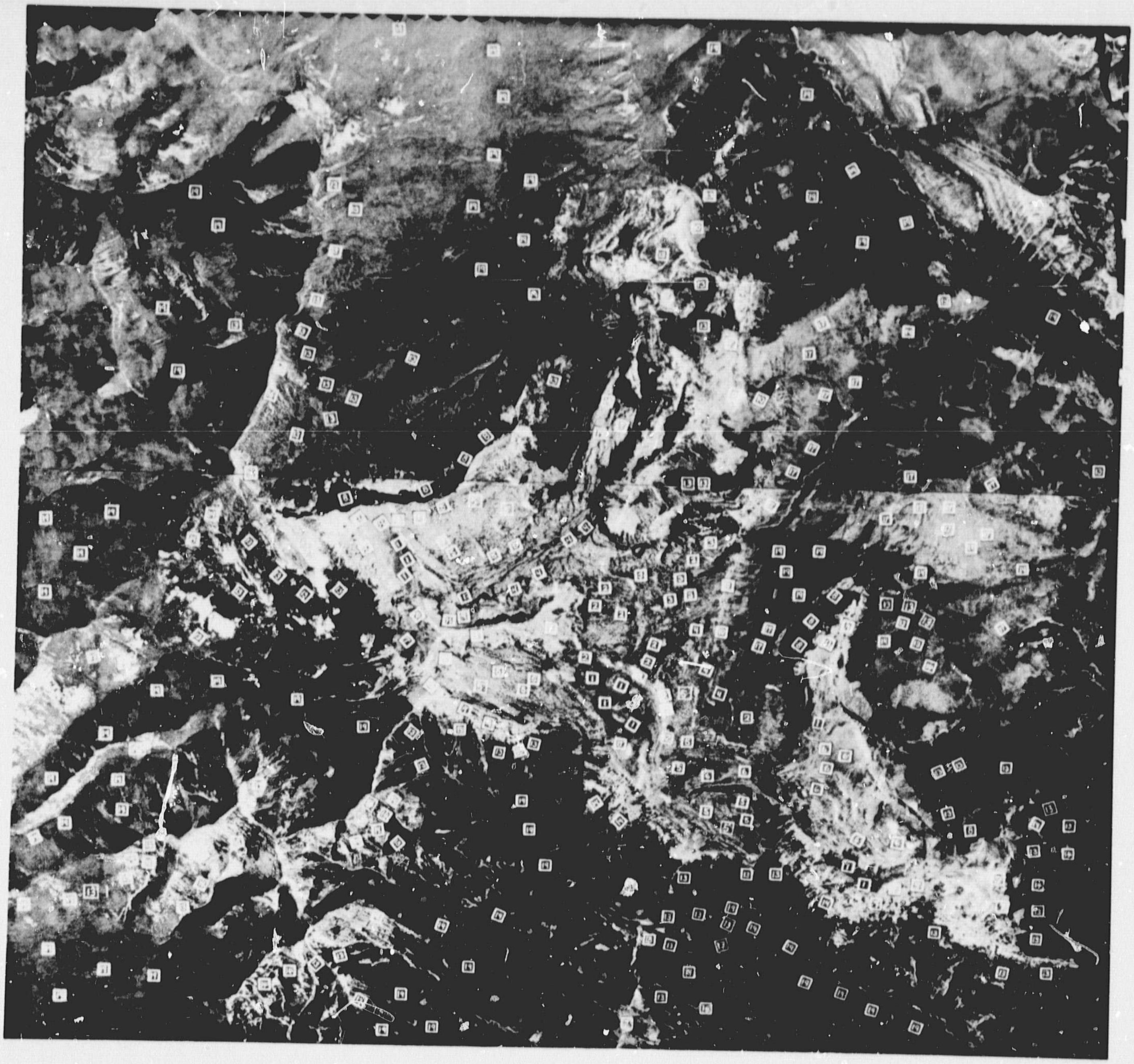


Fig. 15 Transects were made through areas adjacent to field test sites to gather quantitative data for vegetation descriptions.

Fig. 16 Orthophoto showing location and distribution of test sites in the Scapegoat area. By superimposing a transparent overlay of the computer thematic map and a contour overlay, both scaled to the orthophoto, it was possible to record color-encoded pixels as correct or incorrect. Test sites that included ecotone areas could also be checked against their thematic designation.



were examined pixel-by-pixel for agreement (or lack of it) between the computer modeling and ground truth for each class. Using a light table, the pixels within the test sites were evaluated for accuracy of computer spectral interpretation of each ELU or ELT. In addition, color-coded enlargements with transparent overlays of test sites were used to check accuracy. The vegetation complexes established through computer-mapping were described in terms of their respective ELUs and ELTs. These also were evaluated for accuracy. The data were finally evaluated for overall accuracy as a function of each of the eight classes and recorded as a percent. Picture element definition (pixel size) did not seriously limit the accuracy of the thematic map; but spectral analysis of the system had definite limitations that will be discussed later.

Secondary Study Areas

After I determined the level of accuracy for the thematic map of Scapegoat, the spectral values (signatures) were extrapolated to secondary study areas, the Slategoat and the Danaher, using multispectral imagery frame 1036-17571 and computer-processed spectral data from the Image

100 computer.

Color thematic maps of 3-inches-to-the-mile (1:21120) for Slategoat and Danaher were checked in the field against ground truth data. Thematic map detail is shown in Fig. 17. This was accomplished using orthophotos and vegetation mapping. Field test sites were established, described, and recorded on the orthophoto maps (Figs. 18 and 19). Test sites for both areas were established within ecological land units and landtypes. Accuracy of the extrapolation was then tested on 234 alpine and 223 subalpine test sites in the secondary, Slategoat, area using the transparency-overlay technique described earlier. Each test site was 2.8 acres (1.1ha) (2.5 pixels). Slategoat lay 27 airline miles (43.5km) north of the primary study area. The Danaher Study Area, adjacent to the primary area, was used to test accuracy in the temperate zone. Each of the 140 test sites in the temperate zone comprised 6.7 acres (2.7ha) (6 pixels).

Ecotone Inclusions

I refined the evaluation of the computer maps with accuracy tests, utilizing ecotone inclusions. Pixel accuracy was first calculated from field test sites to be correct or incorrect as described above. Those pixels

64

Fig. 17 Three-inches-to-the-mile (1:21120) enlargement of a section of the Scapegoat third generation computer map (Fig. 29). First and second generation color-encoded maps at this scale were used in the field to check accuracy and to relate topography, landforms and vegetation to spectral classification.


7600
x8013
8000
7600

Fig. 18 Test sites, established in a variety of landtypes, were evaluated and described in the field.

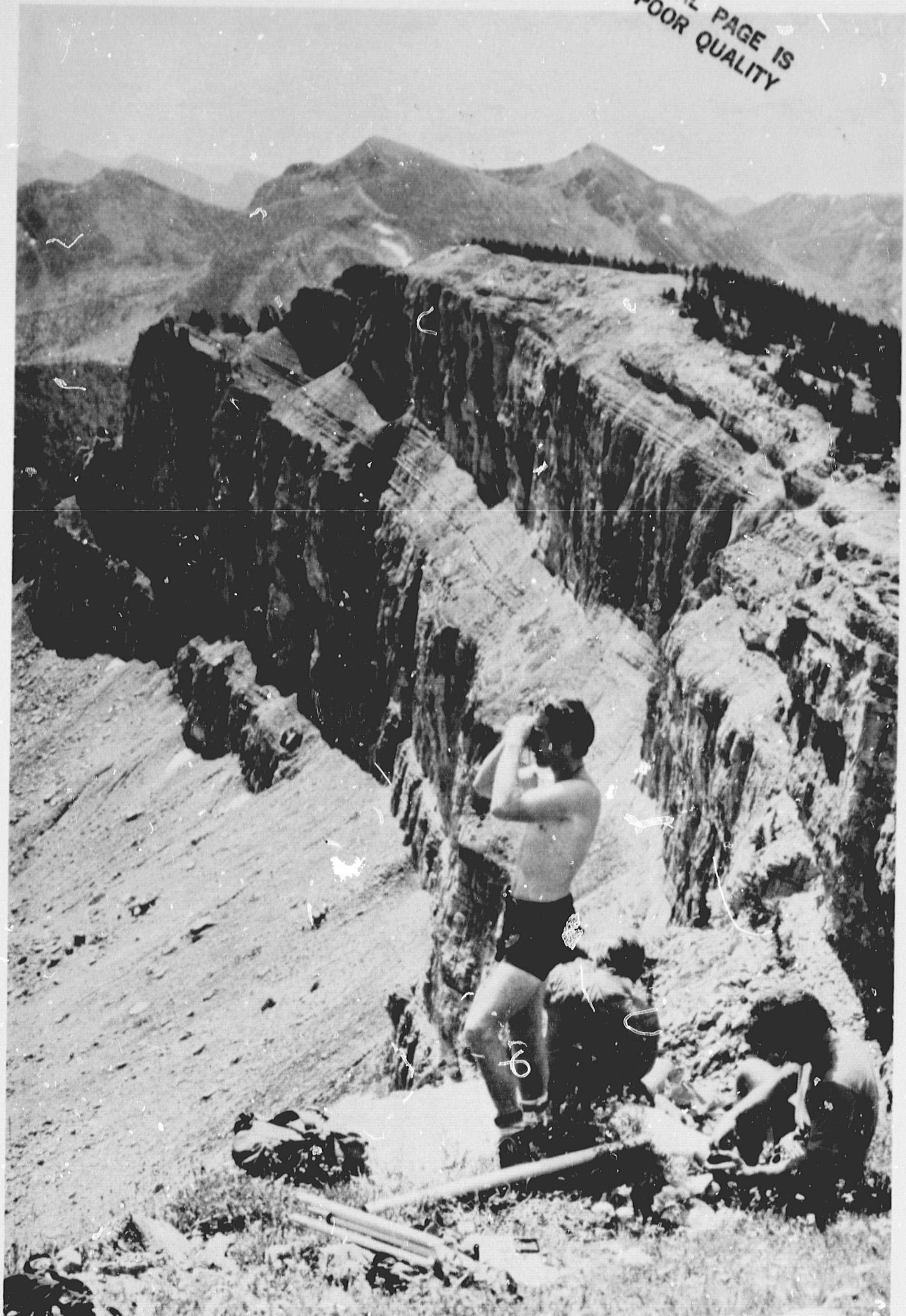


Fig. 19 Field test sites were described, then recorded on orthophotos. Training sites were also located on these maps which were later used to locate the sites on the digital display of the MSS imagery.

classified as incorrect because they did not conform to ground truth data of test sites were then re-examined. Some of the incorrectly classified pixels were found to represent ecotones or gradients between the theme tested and the theme or themes in which they appeared. For example, some pixels lying within the Pinus albicaulis theme (light green) registered as the mixed coniferous forest theme (violet, Figs. 11 and 28) and vice versa. Inspection of aerial photographs showed that ground truth for many of these pixels were transitions between the lighter Pinus albicaulis forest canopy and the heavier canopy of the mixed coniferous forests, or transitions between the grass-shrublands and the sparsely timbered P. albicaulis forests. Transition areas were either upper or lower limits between two or more color encoded themes. Pixels representing ecotones, but "incorrectly" classified by the computer, were considered correct and assigned to the theme being tested.

When testing the theme for the Xeric Pinus Albicaulis Forest Complex, those pixels determined to represent ecotonal or vegetation gradients between the Mixed Coniferous Forest Complex on the one hand and the Subalpine Parkland

complex on the other were assigned to the Xeric Pinus Albicaulis Forest Complex. To further illustrate the procedure: If a test site of 5 acres (2.0ha) in the Xeric Pinus Albicaulis Forest Complex registered 4 pixels correct in the green theme (gray level values of 10-16 μm in band 5 and 16-33 μm in band 7), with half a pixel "incorrect" in the dark blue theme (Subalpine Parkland Complex - gray level values of 5-18 μm in band 5 and 5-15 μm in band 7), then the "incorrect" half pixel was considered correct if examination of the test site on color photos indicated a vegetational gradient at the appropriate site within the test area. If it did not meet this criterion, it was considered as an incorrect classification. Classification testing by several team members justified this procedure. Testing showed that these areas would have been correctly classified if assigned to the extreme limits of either theme where intergredations of vegetation types occurred. When the field test sites were established we did not recognize that in some instances, they were not completely homogenous for the signature being tested and that ecotone areas were included. The deviation from the original standards set for the training areas were so subtle they escaped initial detection in the field. However, they

were later detected on color photographs when re-examined. Additional field checking showed that ecotone areas of pixel size were indeed present within and immediately adjacent to many test sites. They were more easily recognized by the computer measuring spectral values than by trained ecologists working on the ground. More rigid standards and more careful designation of test sites would help remedy the problem but not eliminate it since 100% homogeniety in test sites is difficult to determine in mixed vegetation types. A reduction in size of test sites to pixel size (1.12 acres) (.45ha) would also reduce the effect of ecotone gradients.

An allowance for ecotone assignment in all themes yielded closer agreement between ground truth data and computer classification. This did not alter the computer map but did enable us to present both best and worst case accuracy tests.

Method of Quantifying Descriptions of Vegetation Complexes

I obtained quantitative descriptions of each vegetation complex by overlaying the ground truth map, Fig. 37, with a transparent, color encoded computer map and transparent grid. Landtypes and forest habitat types

were quantified by a midpoint grid tabulation. All vegetation complexes within the three climatic zones in the Scapegoat Study Area were sampled as well as those for the secondary study areas. For example, the Xeric Pinus Albicaulis Forest Complex of the subalpine zone in the Scapegoat area when sampled with the grid overlay technique was shown to have the following composition:

Vegetation Complex	Description and Composition by Habitat Types & Phases	Occurrence	Percent Occurrence (Composition)
GROUP V: XERIC PINUS ALBICAULIS FOREST COMPLEX; predom. E, SE, S, SW exposures; light canopy cover (15-35%).	Climax Vegetation: Abies lasiocarpa		
	831 Abies lasiocarpa/ Luzula hitchcockii- Vaccinium scoparium	134	42
	820 Abies lasiocarpa (Pinus albicaulis)/ Vaccinium scoparium	70	22
False color: Green	850 Pinus albicaulis- Abies lasiocarpa	47	14
	010 SCREE	23	7
	832 Abies lasiocarpa/ Luzula hitchcockii- Menziesia ferruginea	15	5
	692 Abies lasiocarpa/ Xerophyllum tenax- Vaccinium scoparium	14	4
	691 Abies lasiocarpa/ Xerophyllum tenax- Vaccinium globulare	9	3
	860 Larix lyallii-Abies lasiocarpa	9	3
	Total	321	100

Thus, the occurrence of forest habitat types 831 and 820 were recorded 134 and 70 times, respectively, in the Xeric Pinus Albicaulis Forest Complex of the subalpine zone. Other habitat types lying within the color theme were recorded as indicated. The percent occurrence of each habitat type represents a quantitative description of the forest composition.

Vegetation descriptions for all complexes were derived in similar manner from ground truth data. The quantitative descriptions of some complexes were roughly field-checked. The results further verified the grid square technique as a precise method of quantifying the vegetation composition of the complexes.

RESULTS

Although the ecological land units, landtypes, and landtype associations delineated to classify the alpine, subalpine, and temperate vegetation for ground-mapping were discrete landforms, the vegetation integraded and varied greatly in cover-density among the units (see Section I). Observations indicated a vegetational density gradient from the rock composing the high ridges and mountain peaks to the heavily turfed alpine meadows. A

similar gradient was evident for the landtypes and the landtype associations. These vegetational gradients were supported by micro-densitometer readings and data from vegetation sampling. This suggested the possibility of combining land units, identified and described in Section I, into larger landform-vegetation groupings, ecologically related, that could be identified on LANDSAT imagery from spectral values. Accordingly, landforms, identified in the field and described in Section I, were first grouped by spectral values and then altitudinally by vegetation composition and plant density. These are the vegetation complexes discussed under methodology (Figs. 21, 22, 23, 25 and 27).

Construction of Computer Maps of Scapegoat

Early in the study I recognized that to develop an accurate vegetation map, supported with a classification based on vegetation characteristics and on spectral values from a LANDSAT frame, I would have to construct several generations of thematic maps showing progressive improvement. Accordingly, a first generation map was field tested. With additional field data, a second generation map was constructed and also field tested. The third and

final thematic map incorporated progressive input from three seasons of field testing and vegetation sampling (Fig. 29).

To construct the second generation map of Scapegoat, 7 vegetation complexes were described using the signatures shown in Fig. 10; a "signature" polygon was employed to differentiate the grass-shrublands of the alpine and subalpine zones. Polygon A (Fig. 13) separated the Alpine Meadow Complex from the Subalpine Parkland Complex at an elevation of 7600 feet (2316m). Seven of ten complexes were color encoded and displayed on a refined second generation map (Fig. 28). Because 3 complexes could not be delineated without utilizing additional "signature" polygons (see METHODS and Fig. 13), I elected to construct a third generation map (Fig. 29), following additional field work. This more precisely defined the spacial zones and the vegetation complexes within them.

Spectral Values for Second and Third Generation Maps of Scapegoat

Signature blocks used in constructing the second generation map (Fig. 28) are presented in Fig. 10. Construction of the third generation map required minor modification of the original signature blocks and, in

addition, the development of two new signatures. Signature values for the third generation map are shown separately for the alpine, subalpine, and temperate zones in Figs. 20, 24, and 26. The most important signature changes in the third generation map occurred in the themes representing the xeric *Pinus albicaulis* and *Pseudotsuga menziesii* forest types and the alpine meadow and subalpine parkland vegetation. Changes in gray level values can be seen by comparing Figs. 20 and 24 with Fig. 10. Values for the two new signatures representing *Equisetum* seepage areas and sedge (*Carex*) meadows are 31 to 40 μm in band 7 and 13 to 29 μm in band 5; and 28 to 31 μm and 12 to 18 μm in bands 7 and 5, respectively (Figs. 20, 24, and 26). The latter signature was adequate for mapping sedge meadows only when used in conjunction with a signature polygon.

Comparison of Area Changes Resulting from Altitude Zoning

A combination of spectral data and elevational zoning permitted the delineation of 13 complexes for the third generation map. Data presented in Tables 4 and 5 show how the use of signature polygons, to designate spacial zones, altered area statistics. The tables also

Fig. 20 Signature blocks for third generation maps--alpine zone above 7600 feet (2316m). Note the difference in these signatures and those shown in Fig. 10; also that a new signature, Equisetum seepage, has been extracted.

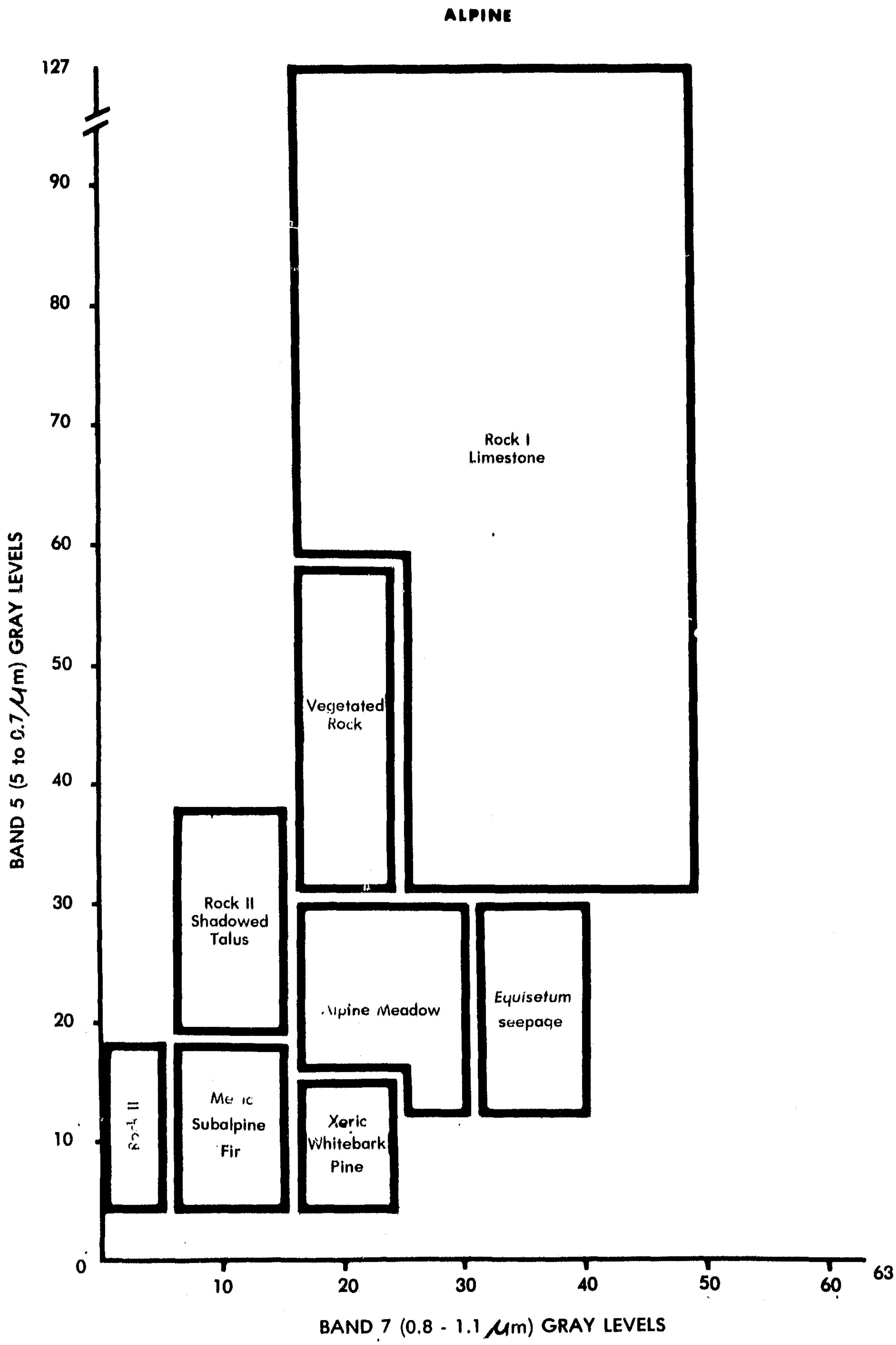
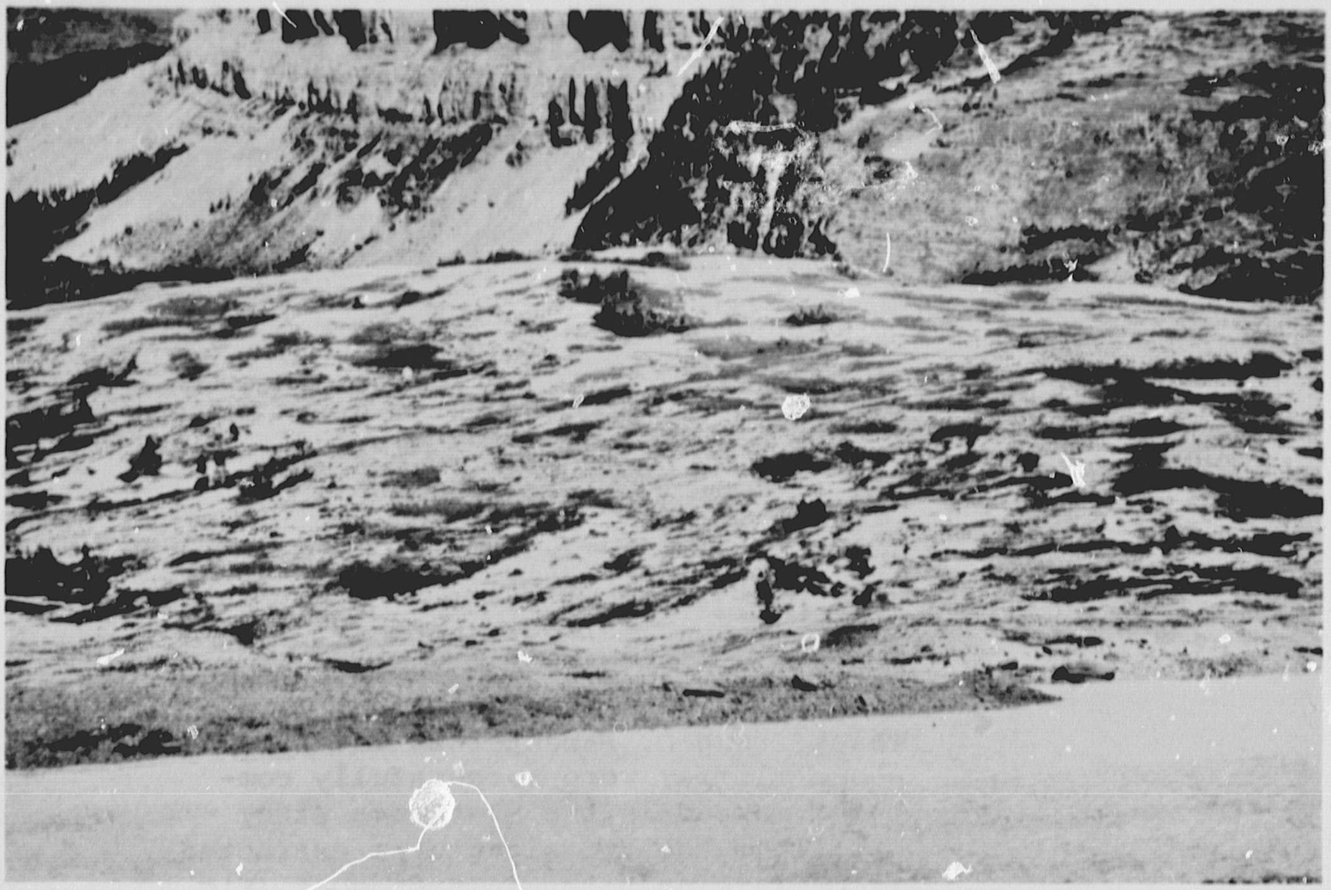

ALPINE
127
90
80
70
60
50
40
30
20
10
0
BAND 5 (5 to 0.7 μm) GRAY LEVELS
Rock I
Limestone
Vegetated
Rock
Rock II
Shadowed
Talus
Alpine Meadow
Equisetum
seepage
Subalpine
Fir
Xeric
Whitebark
Pine
10
20
30
40
50
60
63
BAND 7 (0.8 - 1.1 μm) GRAY LEVELS

Fig. 21 The two photographs show typical Alpine Meadow Complex in the Scapegoat and Slategoat Study Areas. The signature (gray level values of 17 to 30 μm in band 5 and 16 to 35 μm in band 7) was extracted from a training site in Scapegoat, upper photograph. When extrapolated to the Slategoat area it was typically represented as shown in lower photograph.

Fig. 22 The two photographs (upper and lower) show the similarity of the Vegetated Rock Complex in two study areas.
The signature (gray level values of 31 to 65 μm in band 5 and 16 to 24 μm in band 7) for the Vegetated Rock was extracted from training sites in the primary study area (top).
When extrapolated to the Slategoat area it was typically represented as shown in lower photograph.



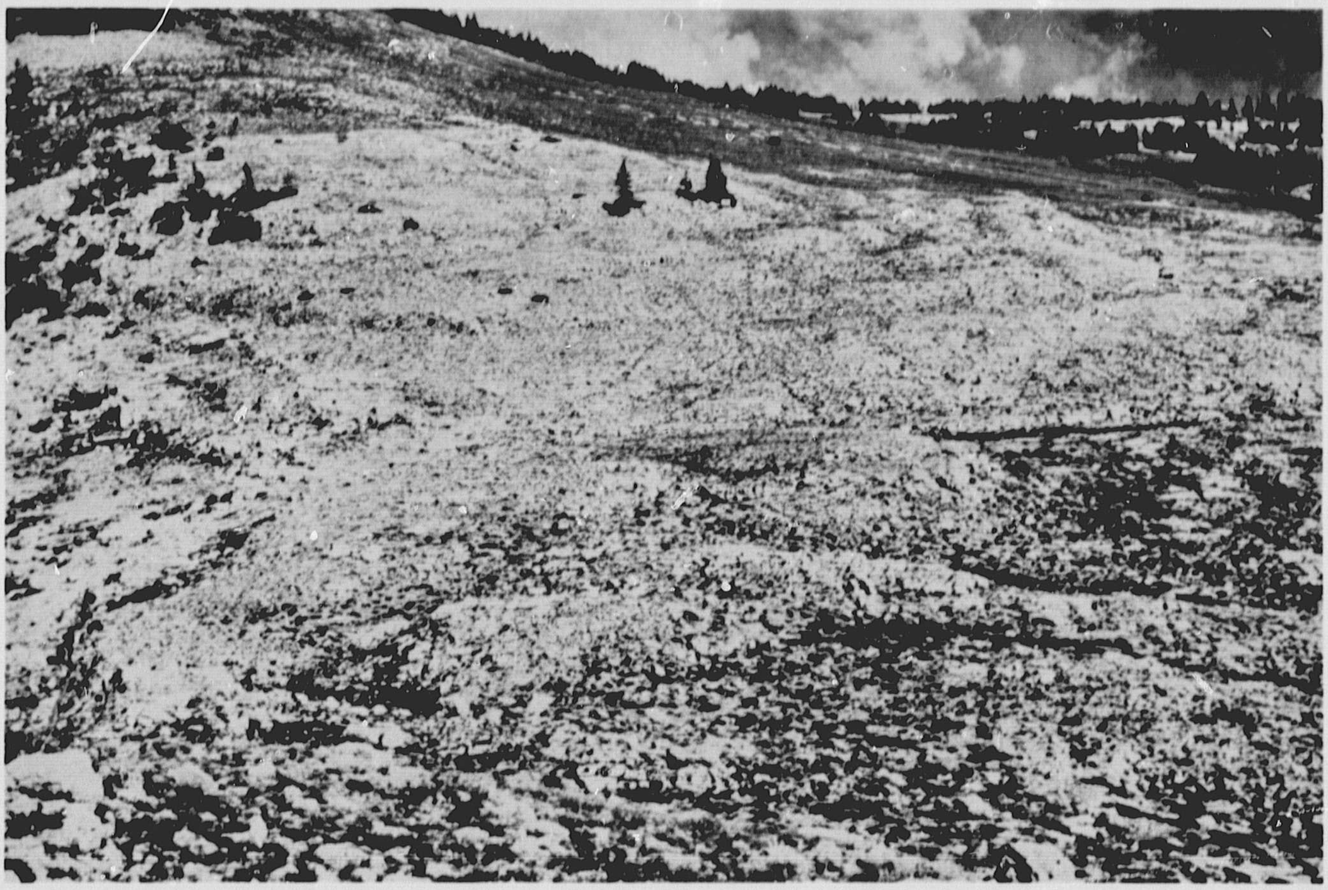


Fig. 23 Top: The Bare Rock Complexes composed of A. Bare Rock in shadow; B. Bare Talus; and C. Parent rock and limestone cliffs, were successfully computer mapped in the Slategoat Study Area from the two signatures extracted from training sites in Scapegoat (Fig. 16) and extrapolated to Slategoat.

Bottom: A typical mosaic of alpine vegetation complexes. Computer mapping accurately delineated the A. Alpine Meadow Complex; B. Vegetated Rock Complex; and C. the Bare Rock Complex in the secondary Slategoat area from signatures extracted in the Scapegoat area.


C
B


A
B
C

Fig. 24 Signature blocks for third generation maps--subalpine zone (7000-7600 feet) (2134-2316m). Note that the signature blocks for this zone are identical to those for the alpine zone, Fig. 20. However, the vegetation complexes represented by the signatures for SCREE and Parkland, have changed with change in elevation. They were separated by elevational zoning (polygons).

SUBALPINE

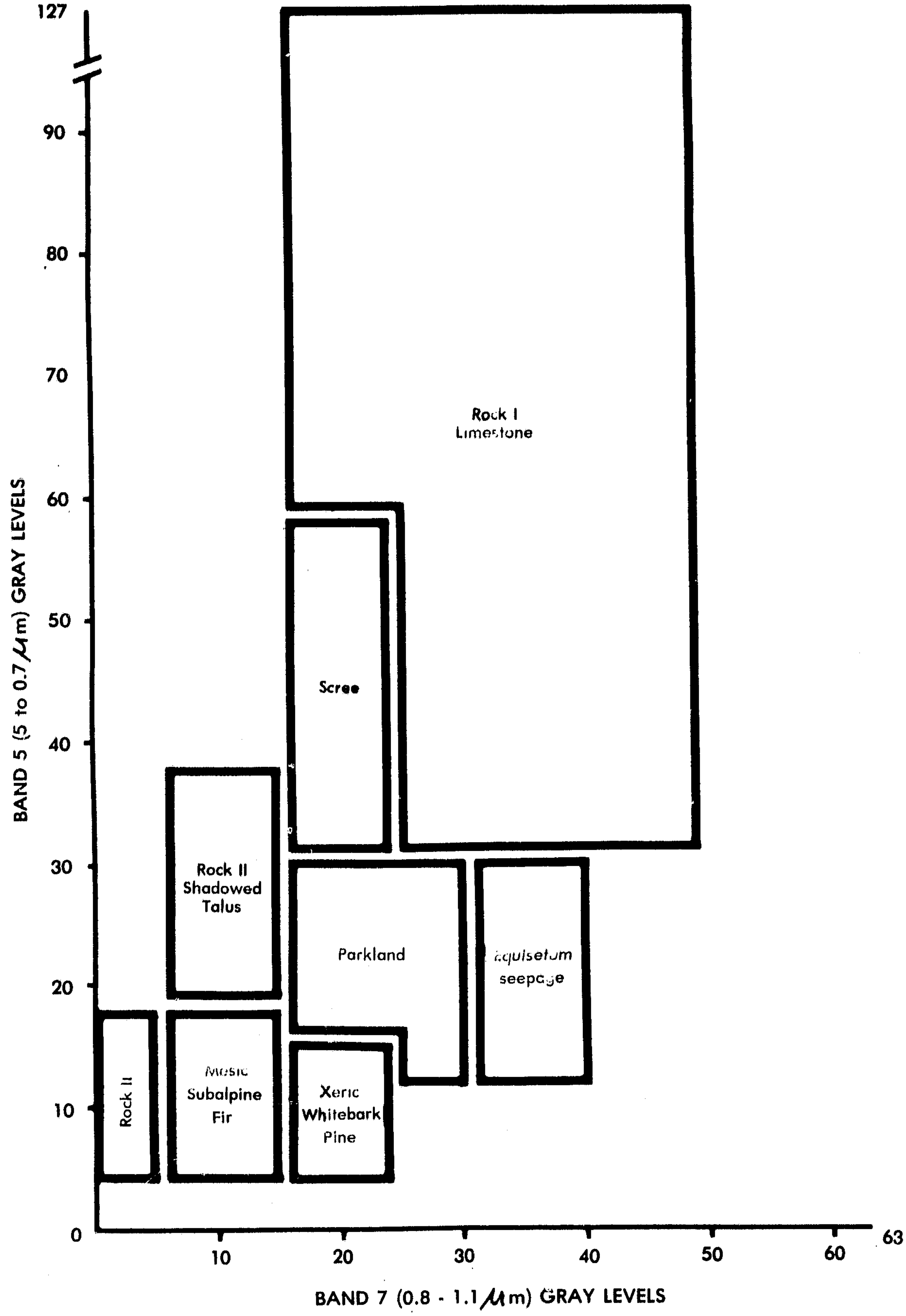

127
90
80
70
60
50
40
30
20
10
0
BAND 5 (5 to 0.7 μm) GRAY LEVELS
Rock I
Limestone
Scree
Rock II
Shadowed
Talus
Parkland
Equisetum
seepage
Rock II
Mesic
Subalpine
Fir
Xeric
Whitebark
Pine
10
20
30
40
50
60
63
BAND 7 (0.8 - 1.1 μm) GRAY LEVELS

Fig. 25 Top: The Xeric Pinus Albicaulis Forest Complex (A) and Subalpine Parkland Complex (B) were first delineated in the Scapegoat area and then extrapolated to the subalpine zone of the secondary Slategoat area. Note the Seral Forest Stages (Burns) (B), a landtype within the parkland complex.

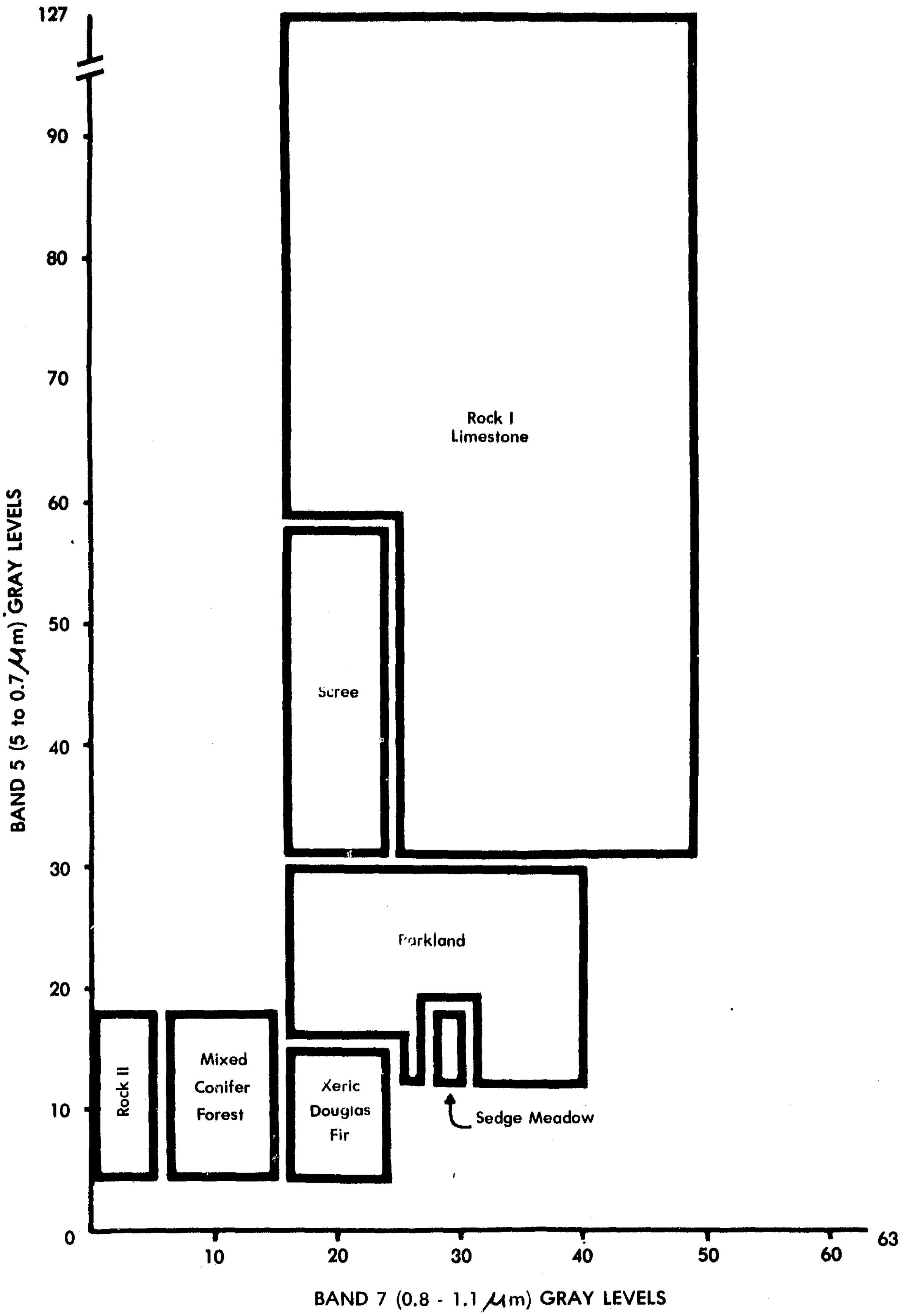
Bottom: The Subalpine Parkland Complex, (A) intergrating with the Temperate Parkland Complex (B). With identical signatures (see Figs. 24 and 26) they were elevationally separated at 7000 feet (2134m) by signature polygons.


A
B


A
B

Fig. 26 Signature blocks for third generation maps--temperate zone, below 7000 feet (2134m). Note that the temperate forest complexes of mesic mixed conifer and xeric Douglas Fir (Pseudotsuga menziesii) are now represented by the same signatures that characterized mesic subalpine fir (Abies lasiocarpa) forests and xeric whitebark pine (Pinus albicaulis) forests in the subalpine zone. A new signature, sedge meadow (Carex-Salix marsh), has been extracted.

TEMPERATE



127
90
80
70
60
50
40
30
20
10
0
Rock I
Limestone
Scree
Parkland
Rock II
Mixed
Conifer
Forest
Xeric
Douglas
Fir
Sedge Meadow
10
20
30
40
50
60
63
BAND 5 (5 to 0.7 μm) GRAY LEVELS
BAND 7 (0.8 - 1.1 μm) GRAY LEVELS

Fig. 27 The Temperate Parkland Complex (A) and the Mixed Coniferous Forest Complex (B) in the secondary Slategoat area were comparable to those in the primary study area. The same applied to the Danaher.

Bottom: The Xeric Pinus Albicaulis Forest Complex (A) and the Mesic Abies Lasiocarpa-Pinus Albicaulis Forest Complex (B) exhibited differences in aspect and canopy cover. These factors were responsible for the unique signatures of the two complexes. Their signatures, shown in Fig. 24, extrapolated accurately to the secondary Slategoat study area.


A


A
B

Table 4 Comparison of Second and Third Generation statistics - Primary study area - Scapegoat.

Complex	Second Generation Percent Area	Third Generation Percent Area
Alpine Meadow	3.94	7.88
*Vegetated Rock	7.32	5.81
**SCREE	-	1.54
Rock I - Limestone	4.62	4.62
Rock II - Shadowed Talus	3.07	3.51
*Xeric Whitebark Pine Forest	17.72	8.01
**Xeric Douglas Fir, Subalpine Fir Forest	-	6.53
*Mixed Coniferous Forest	47.88	27.01
**Mesic Subalpine Fir Forest	-	20.25
*Subalpine Parkland	15.50	8.35
**Temperate Parkland	-	6.03
Sedge Meadow	-	.03
Equisetum Seepage	-	.24
Unclassified	-	.23
Total	100.05	100.01
Total Pixels	44,426	44,253
Total Acres	49,757	49,563
Total Hectares	20,125	20,047

*2nd generation complex from which subdivision was derived.
**Subdivision of 2nd generation complex.

Table 5 Comparison of Second and Third Generation statistics - Secondary study area - Slategoat.

Complex	Second Generation Percent Area	Third Generation Percent Area
Alpine Meadow	3.03	5.26
*Vegetated Rock	6.44	3.03
**SCREE	-	3.39
Rock I - Limestone	5.50	5.49
Rock II - Shadowed Talus	4.11	4.79
*Xeric Whitebark Pine Forest	17.16	4.14
**Xeric Douglas Fir, Subalpine Fir Forest	-	9.86
*Mixed Coniferous Forest	43.49	33.78
**Mesic Subalpine Fir Forest	-	9.32
*Subalpine Parkland	20.30	8.80
**Temperate Parkland	-	11.65
Sedge Meadow	-	.17
Equisetum Seepage	-	.35
Unclassified	-	-
Total	100.03	100.03
Total Pixels	76,962	76,962
Total Acres	86,197	86,197
Total Hectares	34,864	34,864

*2nd generation complex from which subdivision was derived.
**Subdivision of 2nd generation complex.

show the second generation source of each zonal subdivision derived for the third generation map. The Vegetated Rock theme of the second generation map was altitudinally separated into Vegetated Rock and SCREE Complexes in the third generation map. This was accomplished by designating a spacial zone from 7600 feet (2316m) and above and another from 7600 to 7000 feet (2316-2134m). Similarly, the xeric Pinus albicaulis forest theme of the second generation map was altitudinally delineated by a signature polygon between 7000 and 7600 feet (2134 and 2316m). Below 7000 feet (2134m) the spectral signature represented the Xeric Abies Lasiocarpa/Pseudotsuga Menziesii Forest Complex. The mixed coniferous forest theme remained unchanged below 7000 feet (2134m) but above this altitude the theme represented the Mesic Abies Lasiocarpa-Pinus Albicaulis Forest Complex. It was spacially zoned to separate it from the Xeric Pinus Albicaulis Forest Complex. The Subalpine and Temperate Parklands were similarly separated at the 7000 foot (2134m) level by signature polygons (Figs. 29, 42, and 43).

Parameters Influencing Spectral Values

A comparison of signature and ground truth data

showed that spectral values could not be resolved for specific habitat types or plant communities but could be obtained for broad ecological situations. These vegetation complexes appeared to be ecologically consistent and related to both aspect and canopy-density. Altitude had little influence on spectral values obtained using the 28 August 1972 LANDSAT-1 scene. The grass-shrublands, at that time of year, exhibited identical signatures throughout the entire altitudinal range of the study site. The same was true of the forest themes. This was not the case early or late in the growing season when (as would be expected) the spectral values of grass-shrublands in the temperate zone differed markedly from those of the subalpine and alpine zones; this was caused by phenological differences associated with altitude.

Aspect

I examined the role of aspect and canopy density separately and in combination, as factors contributing to the spectral values developed for forest and grass-shrubland vegetation. This was done for both the subalpine and temperate zones and they were quantified using the grid square technique.

Within the subalpine zone 50.0% of 1020 recorded aspects were oriented E-SW, 48.0% W-NE, and 2% zero aspect or flatland. Aspects were grouped for each of three subalpine vegetation complexes (Table 6) and compared with the same range of aspects for the subalpine zone as a whole. The comparison showed that each of the three vegetation complexes was uniquely aspect oriented. The Xeric Pinus Albicaulis Forest Complex had 74% E-SW exposures or 24% above the value of 50% for the entire zone. This same complex had only 25% W-NE exposures or 23% less than the value for the zone as a whole. The opposite situation prevailed for the Mesic Abies Lasiocarpa-Pinus Albicaulis Forest Complex with 25% E-SW exposures and 75% W-NE. Thus, I concluded that the Xeric Pinus Albicaulis Forest Complex was predominantly E-SW oriented and the Mesic Abies Lasiocarpa-Pinus Albicaulis Forest Complex was oriented predominantly W-NE. The Subalpine Parkland Complex exhibited a predominantly E-SW exposure with xeric conditions prevailing.

Data for the Slategoat area (Table 7) displayed a similar relationship between the forest complexes and aspect. However, the Subalpine Parkland Complex was more strongly oriented W-NE than in the Scapegoat area. I

Table 6 Aspectual distribution of vegetation classes in the subalpine zone of the Scapegoat Study Area (1020 samples).

Percent Aspect for Zone		Percent Aspect of Vegetation Classes: Xeric Pinus albicaulis Forest Complex	Mesic Abies lasiocarpa/ Pinus albicaulis Forest Complex	Subalpine Parkland Complex
E	18			
SE	10	74	25	69
S	13	(+24)	(-25)	(+19)
SW	9			
Subtotal	50			
W	12			
NW	6	25	75	26
N	19	(-23)	(+28)	(-22)
NE	11			
Subtotal	48			
No Aspect	2	1	1	5
		(-1)	(-1)	(+3)
Total	100	100	101	100

(+ or -) = a positive or a negative deviation of the forest complex aspect subtotals (percent) from the subtotals of all E, SE, S and SW or W, NW, N, NE aspects recorded for the zone.

Table 7 Aspectual distribution of vegetation classes in the subalpine zone of the Slate-goat Study Area (512 samples).

Percent Aspect for Zone		Percent Aspect of Vegetation Classes: Xeric Pinus albicaulis Forest Complex	Mesic Abies lasiocarpa/ Pinus albicaulis Forest Complex	Subalpine Parkland Complex
E	10			
SE	9	82	31	46
S	22	(+29)	(-22)	(-7)
SW	13			
Subtotal	54			
W	23			
NW	11	18	69	54
N	7	(-29)	(+22)	(+1)
NE	5			
Subtotal	46			
Total	100	100	100	100

attributed this to extensive burns on the W-NE exposures which greatly altered the forest canopy and thus the canopy-aspect relationships.

The forest complexes of both the Scapegoat and Slategoat Study Areas were definitely aspect related, with xeric conditions prevailing on the E-SW exposures and mesic on the W-NE. Since moisture conditions strongly influence stand density and canopy coverage, I suspected that differences in canopy density (as they relate to moisture and these in turn to aspect) were primarily responsible for differences in gray level readings and thus the unique signatures of the two forest themes.

Canopy

Comparison of ground truth data with the forest theme signatures used to develop the first and the second generation computer maps indicated a direct relation between canopy density and the gray level values. Other workers have shown similar relationships (Hoffer et al. 1975). Field estimates of canopy cover (using the technique of Pfister et al. 1977) were compared with microdensitometer readings. Results indicated field workers could ocularly estimate canopy cover with reasonable

accuracy in three general categories. These were heavy (H) 50% and greater; moderate (M) 35-50%, and light (L) 15-35%. Less than 15% was classified as grass-shrublands, and associated landtypes of the Subalpine and Temperate Parkland.

Canopy cover was estimated for forest complexes in both the subalpine and temperate zones and correlated with aspect data (see METHODS). This showed a strong relationship between canopy density and eight major aspects (Tables 6 and 7).

Within the xeric _Pinus albicaulis_ forest theme (light green, Fig. 28) 86.7% of all canopy samples were designated light (L). This light canopy was distributed between the 2 aspect groups with 73.3% occurring among the E-SW aspects and 13.3% among the W-NE aspects (Tables 8 and 10). Within the 2 aspect groupings, 83.3% of all samples occurred among E-SW aspects and 16.6% among the W-NE aspects; 86.7% of all samples were designated light-canopied. The xeric _Pinus albicaulis_ theme, then, was described as a xeric forest of light canopy occurring primarily on E-SW aspects. Thus, it was termed the Xeric Pinus Albicaulis Forest Complex.

The mesic _Abies lasiocarpa/Pinus albicaulis_ forest

theme was sampled similarly, but showed a reversed canopy-aspect relationship. The distribution of aspect for this theme showed that 68.3% of the samples occurred among the W-NE aspects and 31.7% occurred on the E-SW aspects. Among all canopies sampled, 83.3% were designated heavy (H) and were distributed between the W-NE aspects (53.3%) and the E-SW aspects (30.0%) (Tables 8 and 10). The mesic *Abies lasiocarpa/Pinus albicaulis* theme was described as a mesic forest of heavy canopy occurring primarily on W-NE aspects. It was termed the Mesic Abies Lasiocarpa/Pinus Albicaulis Forest Complex.

I concluded that the canopy density of the forest largely determined the gray level values characterizing the two forest complexes of the subalpine zone. Canopy density, in turn, was largely determined by moisture conditions governed by aspect. Therefore, I employed moisture and aspect designations to broadly describe the two forest complexes.

The signatures derived for the xeric (light green) and mesic (violet) themes in the temperate zone were identical to those in the subalpine zone, Figs. 24 and 26. As Tables 9 and 11 show, the canopy-aspect relationships were also similar. As would be expected, the

Table 8 Aspectual distribution of canopy density in the Subalpine Forest Complexes of the Scapegoat Study Area (7600-7000 feet).*

	Xeric Pinus albicaulis Forest Complex (60 samples)							Mesic Abies lasiocarpa/Pinus albicaulis Forest Complex (60 samples)						
	Canopy Occurrence			Percent Canopy Occurrence				Canopy Occurrence			Percent Canopy Occurrence			
Aspect	H	M	L	H	M	L	Total	H	M	L	H	M	L	Total
E	0	1	14	0	1.7	23.3		5	0	0	8.3	0	0	
SE	1	0	10	1.7	0	16.7		1	0	0	1.7	0	0	
S	0	4	13	0	6.7	21.7		6	0	0	10.0	0	0	
SW	0	0	7	0	0	11.7		6	1	0	10.0	1.7	0	
Subtotal	1	5	44	1.7	8.3	73.3	83.3	18	1	0	30.0	1.7	0	31.7
W	0	0	1	0	0	1.7		10	1	2	16.7	1.7	3.3	
NW	0	0	0	0	0	0		5	2	0	8.3	3.3	0	
N	0	1	3	0	1.7	5.0		10	1	1	16.7	1.7	1.7	
NE	0	1	4	0	1.7	6.7		7	2	0	11.7	3.3	0	
Subtotal	0	2	8	0	3.3	13.3	16.6	32	6	3	53.3	10.0	5.0	68.3
Total	1	7	52	1.7	11.7	86.7	99.9	50	7	3	83.3	11.7	5.0	100.0

*Canopy cover densities recorded as Heavy (H) 50% and greater; Moderate (M) 35-50%; Light (L) 15-35%, Ocular estimates.

Table 9 Aspectual distribution of canopy density in the Temperate Forest Complexes of the Scapegoat Study Area (< 7000 feet).*

Aspect	Xeric Temperate Forest Complex (60 samples) Canopy Occurrence H	M	L	Percent Canopy Occurrence H	M	L	Total	Mixed Coniferous Temperate Forest Complex (60 samples) Canopy Occurrence H	M	L	Percent Canopy Occurrence H	M	L	Total
E	0	3	9	0	5.0	15.0		8	0	0	13.4	0	0	
SE	0	3	12	0	5.0	20.0		2	0	0	3.3	0	0	
S	2	1	12	3.3	1.7	20.0		2	0	0	3.3	0	0	
SW	0	1	5	0	1.7	8.3		6	0	0	10.0	0	0	
Subtotal	2	8	38	3.3	13.4	63.3	80.0	18	0	0	30.0	0	0	30.0
W	0	1	2	0	1.7	3.3		6	2	1	10.0	33.3	50.0	
NW	0	1	0	0	1.7	0		9	0	0	15.0	0	0	
N	0	1	1	0	1.7	1.7		8	3	1	13.4	50.0	50.0	
NE	0	0	6	0	0	10.0		11	1	0	18.3	16.7	0	
Subtotal	0	3	9	0	5.1	15.0	20.1	34	6	2	56.7	10.0	3.3	70.0
Total	2	11	47	3.3	18.5	78.3	100.1	52	6	2	86.7	10.0	3.3	100.0

*Canopy cover densities recorded as Heavy (H) = 50% and greater; Moderate (M) 35-50%; Light (L) 15-35%, Ocular estimates.

Table 10 Summary of aspectual distribution of canopy density in the Subalpine Forest Complexes of the Scapegoat Study Area (7600-7000 feet).

Percent Aspects - Xeric Forest Complex	Percent Canopy Occurrence H	M	L	Percent Total Canopy	
E to SW exp. (74)	2	8	74	84	Green Theme (Sig.)
W to NE exp. (25)	0	3	13	16	
Total	2	12	87	100	
Percent Aspects - Mesic Forest Complex					
W to NE exp. (75)	53	10	5	68	Violet Theme (Sig.)
E to SW exp. (25)	30	2	0	32	
Total	83	12	5	100	

Table 11 Summary of aspectual distribution in the Temperate Forest Complexes of the Scapegoat Study Area ($\angle$ 7000 feet).

Percent Aspects- Xeric Forest Complex	Percent Canopy Occurrence H	 M	 L	Percent Total Canopy	
E to SW exp. (75)	3	14	63	80	Green Theme (Sig.)
W to NE exp. (19)	0	5	15	20	
Total	3	19	78	100	
Percent Aspects- Mesic Forest Complex					
W to NE exp. (63)	57	10	3	70	Violet Theme (Sig.)
E to SW exp. (30)	30	0	0	30	
Total	87	10	3	100	

vegetation compositions of these temperate xeric and mesic forest complexes were quite different from their ecological counterparts in the subalpine zone. Those in the temperate zone were termed the Xeric Abies Lasiocarpa/ Pseudotsuga Menziesii Forest Complex and the Mixed Coniferous Forest Complex. I further concluded that, as in the subalpine zone, the two signatures consistently represented habitat types distinct for xeric and mesic conditions. Therefore, though the spectral reflectance values were primarily determined by canopy density, each signature consistently represented a specific complex of forest habitat types. This will be discussed in detail later.

Elevation

The vegetation complexes represented by the signatures (Figs. 20, 24, and 26) occurred through three climatic zones. The signatures' gray level values were determined primarily by canopy density and represented vegetation conditions that were aspect oriented, which in turn reflected moisture conditions. The limits of tree growth (timberline) occurred at about 7600 feet (2316m). This elevation served to demarcate the changes in vegetation from the subalpine to the alpine zone.

Field evidence (Section I) indicated a marked change in the species composition of the vegetation at about 7000 feet (2134m). This was evident from the occurrence of specific forest habitat types. At 7000 feet (2134m) those habitat types, characteristic of the subalpine zone, (Pfister et al. 1977) phased into those characteristic of the temperate zone forests. In order to describe the vegetation complexes represented by each signature (within each of the three climatic zones) I delineated elevational contours where zonal changes in vegetation occurred.

The grid sampling technique (see METHODS) was used to sample forest habitat types along the 7000 foot (2134m) contour and also along the 7200 foot (2195m) and 6800 foot (2073m) contour lines. *Pinus albicaulis* was selected as the indicator species for the subalpine forest habitat types and *Pseudotsuga menziesii* for the temperate forests. I interpreted the evidence of forest habitat changes presented in Table 12 as justification for using 7000 feet (2134m) as a demarcation between the subalpine and temperate zones. Between 7200 and 7400 feet (2195 and 2256m), 91% of the forest habitat types (including SCREE) were those in which *Pinus albicaulis* was common. At 7000 feet (2134m) this percentage was 36%; with habitat types

Table 12 Evidence of Change in Forest Habitat Types Related to Elevation.

Habitat Types and Phases (Sample Size) (Elevation)	(227) 7200-7400 feet	(303) 7000 feet	(277) 6600-6800 feet
Group I			
*831 Abies lasiocarpa/Luzula hitchcockii-Vaccinium scoparium	42	9	
820 Abies lasiocarpa(Pinus albicaulis)/Vaccinium scoparium	21	16	1
832 Abies lasiocarpa/Luzula hitchcockii-Menziesia ferruginea	17	6	1
860 Larix lyallii-Abies lasiocarpa	4		
850 Pinus albicaulis-Abies lasiocarpa	4	2	
010 SCREE	3	2	
Subtotal	91	36	2
Group II			
**670 Abies lasiocarpa/Menziesia ferruginea	3	25	33
692 Abies lasiocarpa/Xerophyllum tenax-Vaccinium scoparium	3	18	23
690 Abies lasiocarpa/Xerophyllum tenax	2	1	2
691 Abies lasiocarpa/Xerophyllum tenax-Vaccinium globulare	1	20	32
650 Abies lasiocarpa/Calamagrostis canadensis			1
320 Pseudotsuga menziesii/Calamagrostis rubescens		1	1
360 Pseudotsuga menziesii/Juniperus communis			1
780 Abies lasiocarpa/Arnica cordifolia			3
750 Abies lasiocarpa/Calamagrostis rubescens			2
Subtotal	9	64	98
Total	100	100	100

* Habitat types having Pinus albicaulis as a major component.
** Habitat types with Pinus albicaulis absent and Pseudotsuga menziesii common.

in which *Pseudotsuga menziesii* was common, 64%. Between 6600 and 6800 feet (2012 and 2073m) 98% of the forest habitat types were those in which *P. menziesii* was common and *P. albicaulis* absent. This evidence for the 7000 foot (2134m) demarcation was further supported by field plots (see Table 12).

By employing spacial zoning at the 7600 and 7000 foot (2316 and 2134m) contours, it was possible to map vegetation with identical spectral values but very different species composition. I accomplished this by using polygons to delineate the respective contours within the computer for differentiation, thus "signature" polygons. In the second generation maps, altitude separations were made only between the Alpine Meadow and Subalpine Parkland Complexes (Fig. 28). In constructing the third generation maps, signature polygons (see METHODS) were employed to altitudinally separate the grass-shrubland and the forest complexes of both the subalpine and temperate zones. The result of this altitude zoning greatly enhanced the spectral mapping technique as shown in Fig. 29.

Classification of Vegetation Complexes of Scapegoat

To develop a vegetation classification and integrate it with the spectral classification, I re-grouped the com-

ponents of the vegetation classification employed in Section I. The descriptive data of the smaller units were consolidated into appropriate larger ones, by regrouping components based on data from field sampling and from ground truth displayed in Fig. 37. Each of ten vegetation groupings, termed vegetational complexes, corresponded with a specific signature or signature polygon. This constituted the eco-spectral classification shown in Fig. 28. For the third generation map the number of vegetation complexes was expanded to thirteen.

Four of the ten complexes described occurred only within the alpine zone. Two of the four supported vascular vegetation and two supported predominantly non-vascular vegetation. These complexes of the alpine zone (7600 - 9000 feet) (2316 - 2743m), described at the 5% level of sampling by their ELU components were:

Alpine Zone

I. Alpine Meadow Complex (color code light blue) with species of Carex a major component. Cushion plants and krummholz usually common.

Alpine Meadow
Alpine Meadow Krummholz
Slab Rock Krummholz
Slab Rock Step Krummholz
Vegetated Talus

II. Vegetated Rock Complex (color code gold) with *Dryas octopetala* a major component with *Carex* and *Festuca* usually common.

Glacial Cirque Basin
Mountain Massif
Fellfield
Semi-vegetated Talus

III. Rock Complex (1) (color code pink) with either vegetation absent or lichens common. Limestone Rock (parent rock or talus).

IV. Rock Complex (2) (color code red) with either vegetation absent or lichens common. Argillite Rock, Rock talus in shadow.

Subalpine Zone

I grouped the forest habitat types and grass-shrubland landtypes of the subalpine zone (between 7000 and 7600 feet) (2134 and 2316m) at the 5% level of sampling into complexes by vegetation composition and general moisture conditions expressed as xeric, mesic, or hydric. The six grass-shrubland landtypes of the subalpine zone (Section I) were consolidated into a single vegetation grouping termed the Subalpine Parkland Complex. Seral forest stages (burns) were considered grass-shrub landtypes because ground cover in the early successional stages was essentially grass-shrubland and the forests stands were lightly stocked.

The forest habitat types were classified into two

forest complexes. These were habitat type-landtype associations (*Abies lasiocarpa* series) with *Abies lasiocarpa* dominant, *Pinus albicaulis* a major component and *Vaccinium scoparium* usually common (Pfister et al. 1977). These vegetation complexes of the subalpine zone described by grouped landtypes, habitat types, and phases were:

V-A. Xeric Pinus Albicaulis Forest Complex (color code light green).

- (831) *Abies lasiocarpa*/*Luzula hitchcockii*-*Vaccinium scoparium*
- (820) *Abies lasiocarpa*(*Pinus albicaulis*)/*Vaccinium scoparium*
- (850) *Pinus albicaulis*-*Abies lasiocarpa*

V-B. Mesic Abies Lasiocarpa-Pinus Albicaulis Forest Complex (color code violet).

- (831) *Abies lasiocarpa*/*Luzula hitchcockii*-*Vaccinium scoparium*
- (832) *Abies lasiocarpa*/*Luzula hitchcockii*-*Menziesia ferruginea*
- (820) *Abies lasiocarpa*(*Pinus albicaulis*)/*Vaccinium scoparium*
- (670) *Abies lasiocarpa*/*Menziesia ferruginea*

VI-A. Subalpine Parkland Complex (color code dark blue) with *Xerophyllum tenax*, *Carex* spp. and *Calamagrostis rubescens* predominating. Forbs varied and abundant. Includes the following landtypes:

- Seral Forest Stages (Burns)
- Wet Forb Grasslands
- Dry Forb Grasslands
- Snowslides
- Ridgetop Glades
- SCREE Slopes

Temperate Zone

I grouped the grass-shrublands and the coniferous forests of the temperate zone (below 7000 feet) (2134m) using the same basic criteria applied to vegetation of the subalpine zone. The forest types, classified into forest complexes, were habitat type-landtype associations with Abies lasiocarpa and Pseudotsuga menziesii dominant. The temperate zone complexes were:

VI-B. Temperate Parkland Complex (color code dark blue). Festuca scabrella, Festuca idahoensis and Carex spp. predominating. Forbs and shrubs varied and abundant. Includes the following landtypes:

Seral Forest Stages (Burns)
Wet Forb Grasslands
Dry Forb Grasslands
SCREE Slopes

VII. Xeric Abies Lasiocarpa Pseudotsuga Menziesii Forest Complex (color code light green). Low water table and with Abies lasiocarpa or Pseudotsuga menziesii generally dominant, Pinus contorta variable. Vaccinium spp. variable.

(691) Abies lasiocarpa/Xerophyllum tenax-Vaccinium globulare
(692) Abies lasiocarpa/Xeropyhllum tenax-Vaccinium scoparium
(820) Abies lasiocarpa(Pinus albicaulis)/Vaccinium scoparium
(670) Abies lasiocarpa/Menziesia ferruginea
(320) Pseudotsuga menziesii/Calamagrostis rubescens
(360) Pseudotsuga menziesii/Juniperus communis
(010) SCREE

VIII. Mixed Coniferous Forests (predominantly mesic sites) (color code violet). *Abies lasiocarpa* predominant with *Pseudotsuga menziesii* variable. *Vaccinium* spp. variable.

(670) *Abies lasiocarpa*/*Menziesia ferruginea*
(691) *Abies lasiocarpa*/*Xerophyllum tenax* *Vaccinium globulare*
(692) *Abies lasiocarpa*/*Xerophyllum tenax*-*Vaccinium scoparium*

Summary Statistics of Rock and Vegetation Complexes for Second Generation Map

Area relationships of the rock (lichens) and vegetation complexes just described are presented in Table 13. The Alpine Meadow and Vegetated Rock Complexes represent 4 and 7% of the total area, respectively. The subalpine and temperate parklands combined are nearly 4 times as extensive as the Alpine Meadow Complex. The xeric and mesic coniferous forest complexes comprise the largest area; 18 and 48%, respectively. The subalpine and temperate complexes can be further separated by altitude zoning. Since this was accomplished with third generation maps, a full discussion of area statistics and their significance will be given later in the text.

Quantitative Description of Vegetation Complexes by Land Units, Landtypes, and Forest Habitat Types

I first described the vegetation complexes (Table 14)

Table 13 Summary of area statistics for vegetation complexes of the second generation map of Scapegoat.

Complexes	Area Pixels	Acres	Hectares	Percent
Alpine Meadow	1746	1956	791	3.94
Vegetated Rock	3248	3638	1471	7.32
Bare Rock I	2051	2297	929	4.62
Bare Rock II Shaded Talus	1358	1521	616	3.07
Xeric Pinus Ablicaulis and Pseudotsuga Menziesii Forest	7870	8814	3565	17.72
Subalpine and Temperate Parkland	6882	7708	3118	15.50
Subalpine and Temperate Mixed Coniferous Forest	21271	23824	9636	47.88
Total	44,426	49,757	20,125	100.05

Note: These summary statistics can be applied directly to the Scapegoat Map -- Fig. 28.

Fig. 28 Scapegoat second generation map with contour overlay.

Six signatures were used to construct Fig. 28. Alpine Meadow and Subalpine Parkland were delineated respectively, above and below the 7600 foot (2316m) contour using signature polygons. By superimposing a contour map over the thematic map, the xeric whitebark pine forests were differentiated from the xeric temperate subalpine fir/douglas-fir forests at the 7000 foot (2134m) contour. The resulting spacial zones were the basis for the signature polygons later used to divide the forest class shown in light green into 2 distinct forest complexes for the third generation map (Fig. 29). These forest complexes were color encoded light green and dark purple in the third generation map, (Fig. 2 9). Similarly the mesic mixed coniferous forests, color-encoded violet, were differentiated (Fig. 29) into a mesic subalpine fir forest above 7000 feet (dark green) and into a mixed coniferous forest below that elevation (light purple). These were then field-checked for accuracy and their vegetation characteristics described. This was accomplished by employing both thematic and vegetation type maps enlarged to 3-inches-to-the mile (1:21120) with contour overlays. Summary statistics are presented in Table 13. A comparison of Fig. 28 with Fig. 11 shows the result of employing spacial zoning to differentiate the Alpine Meadows from the Subalpine and Temperate Parklands.

SECOND GENERATION
LANDSAT COMPUTER THEMATIC MAP OF GRIZZLY BEAR HABITAT
SCAPEGOAT WILDERNESS
MONTANA
1976

Vegetation/Rock Classes (Spectral Themes)

- Alpine Meadow
- Bare Talus Slopes and Argillite Rock
- Parent Rock (Largely Limestone)
- Subalpine Fir - Whitebark Pine Forest
- Vegetated Rock
- Subalpine and Temperate Parkland
- Subalpine and Temperate Mixed Coniferous Forests
- Temperate Subalpine Fir Douglas Fir Forest

displayed in Fig. 28, by the number of times a specific ELU, ELT, or HT occurred within a given vegetation complex. The grid overlay midpoint intersect procedure in Complex VI (Table 14) was used for this purpose. For example, the Abies lasiocarpa/Luzula hitchcockii habitat type, Vaccinium scoparium phase (831), was represented in 177 of 476 grid squares, for a 37% occurrence within the Mesic Abies Lasiocarpa/Pinus Albicaulis Forest Complex. Habitat types 832 and 820 had 19 and 12% occurrence, respectively, with other habitat types also occurring as shown in Table 14. The percent occurrence of all habitat types within the complex quantitatively expressed the forest composition. Thus, each of the 13 complexes shown in Fig. 29 is quantitatively described with its area percentage.

To determine the general vegetation characteristics and area percentages of the thirteen complexes displayed in Fig. 29, the reader is referred to Table 14. For example, the light green encoded area representing the Xeric Pinus Albicaulis Forest Complex comprised 3966 acres (1605ha) or 8.01% of the total Scapegoat area. It is composed of 42, 22, and 14% forest habitat types 831, 820, and 850, respectively, with percentages of other forest habitat types as recorded in Table 14.

Table 14 Description of vegetation complexes representing a spectral classification for the third generation computer map of the Scapegoat Stude Area.

ALPINE CLIMATIC ZONE (>7600')

Vegetation Complex (Class)	Percent Area (Acres)	Description and Composition by Ecological Land Units	Occurrence	Percent Composition*
Complex I: ALPINE MEADOW	7.88	Climax Vegetation: Carex spp.		
		Alpine Meadow Krummholz	28	32
		Alpine Meadow	22	25
		Slab Rock Krummholz	20	23
		Slab Rock Steps	15	17
		Vegetated Talus	3	3
		Total	88	100
Complex II: VEGETATED ROCK	5.81	Climax Vegetation: Dryas octopetala		
		Glacial Cirque Basin	43	29
		Semi-vegetated Talus	33	23
		Mountain Massif	27	18
		Fellfield	21	14
		Bare Talus	16	11
		Parent Rock-Limestone	8	5
		Total	148	100
Complex III: BARE ROCK I	4.62	Climax Vegetation: Lichens		
		Parent Rock-Limestone	30	45
		Bare Talus	22	33
		Semi-vegetated Talus	8	12
		Snowfield and Snowfield Sinks	5	7
		Fellfield	2	3
		Total	67	100
Complex IV: BARE ROCK II	3.51	Climax Vegetation: Lichens		
		Bare Talus in shadow	22	71
		Parent Rock-Argillite	9	29
		Total	31	100

*Percent composition of vegetation complexes was calculated employing the grid overlay with the third generation computer map (SEE METHODS).
Note: For botanical details of the alpine ecological land units, see Tables 1-12 Section I Appendix.

Table 14 Continued.

SUBALPINE CLIMATIC ZONE (7600'-7000')

Vegetation Complex (Class)	Percent Area (Acres)	Description and Composition by Forest Habitat Types or by Ecological Landtypes	Occurrence	Percent Occurrence (Composition)*
Complex V. XERIC PINUS ALBICAULIS FOREST; predom. E, SE, S, SW exposures; light canopy cover. (15-35%).	8.01	Climax Vegetation: Abies lasiocarpa		
		831 Abies lasiocarpa/Luzula hitchcockii-Vaccinium scoparium	134	42
		820 Abies lasiocarpa(Pinus albicaulis)/Vaccinium scoparium	70	22
		850 Pinus albicaulis-Abies lasiocarpa	47	14
		010 SCREE	23	7
		832 Abies lasiocarpa/Luzula hitchcockii-Menziesia ferruginea	15	5
		692 Abies lasiocarpa/Xerophyllum tenax-Vaccinium scoparium	14	4
		691 Abies lasiocarpa/Xerophyllum tenax-Vaccinium globulare	9	3
		860 Larix lyallii-Abies lasiocarpa	9	3
		Total	321	100
Complex VI: MESIC ABIES LASIOCARPA/PINUS ALBICAULIS FOREST; predom. NE, N, NW, W exposure; moderate to heavy canopy cover. (35%).	20.25	Climax Vegetation: Abies lasiocarpa		
		831 Abies lasiocarpa/Luzula hitchcockii-Vaccinium scoparium	177	37
		832 Abies lasiocarpa/Luzula hitchcockii-Menziesia ferruginea	90	19
		820 Abies lasiocarpa(Pinus albicaulis)/Vaccinium scoparium	59	12
		670 Abies lasiocarpa/Menziesia ferruginea	53	11
		850 Pinus albicaulis-Abies lasiocarpa	24	5
		860 Larix lyallii-Abies lasiocarpa	22	5

Table 14 Continued.

Vegetation Complex (Class)	Percent Area (Acres)	Description and Composition by Forest Habitat Types or by Ecological Landtypes	Occurrence	Percent Occurrence (Composition)*
Complex VI: (Continued):		691 Abies lasiocarpa/Xerophyllum tenax-Vaccinium globulare	22	5
		690 Abies lasiocarpa/Xerophyllum tenax	14	3
		692 Abies lasiocarpa/Xerophyllum tenax-Vaccinium scoparium	12	2
		650 Abies lasiocarpa/Calamagrostis canadensis	3	1
		Total	476	100
Complex VII: SUBALPINE PARKLAND	8.35	Climax Vegetation: Festuca spp., Abies lasiocarpa		
		SCREE - with trees	94	42
		Xeric-mesic seral forest stages (burns)	72	32
		Xeric subalpine grass-shrublands	57	26
		Total	223	100
Complex VIII: EQUISETUM SEEPAGE	.24	Equisetum arvense, Pedicularis groenlandica	1	100
Complex XIII: SCREE (Grass-shrub)	1.54	Festuca idahoensis, Carex spp. Ribes spp.	-	-

Note: For botanical details of the subalpine ecological landtypes, See Table 2, Section I, and for the forest habitat types see Pfister et al. (1977)

Table 14 Continued.

TEMPERATE CLIMATIC ZONE (<7000')

Vegetation Complex (Class)	Percent Area (Acres)	Description and Composition by Forest Habitat Types or by Ecological Landtypes	Occurrence	Percent Occurrence (Composition)*
Subcomplex IXA: XERIC ABIES LASIOCARPA FOREST; predom. E, SE, S SW exposures; light canopy cover (15-35%)	6.53	Climax Vegetation: Abies lasiocarpa		
		691 Abies lasiocarpa/Xerophyllum tenax-Vaccinium globulare	75	42
		692 Abies lasiocarpa/Xerophyllum tenax-Vaccinium scoparium	67	38
		820 Abies lasiocarpa(Pinus albicaulis)/Vaccinium scoparium	12	7
		670 Abies lasiocarpa/Menziesia ferruginea	8	5
		010 SCREE	7	4
		750 Abies lasiocarpa/Calamagrostis rubescens	6	3
		650 Abies lasiocarpa/Calamagrostis canadensis	2	1
		Total	177	100
Subcomplex IXB: XERIC PSEUDOTSUGA MENZIESII FOREST; predom. E, SE, S, SW exposures; light canopy cover. (15-35%).		Climax Vegetation: Pseudotsuga menziesii		
		320 Pseudotsuga menziesii/Calamagrostis rubescens	18	52
		360 Pseudotsuga menziesii/Juniperus communis	13	37
		010 SCREE	4	11
		Total	35	100
Complex X: MIXED CONIFEROUS FOREST; predom. NE, N, NW, W exposures; heavy canopy (35%).	27.01	Climax Vegetation: Abies lasiocarpa or Pseudotsuga menziesii		
		670 Abies lasiocarpa/Menziesia ferruginea	278	43
		691 Abies lasiocarpa/Xerophyllum tenax-Vaccinium globulare	179	27
		692 Abies lasiocarpa/Xerophyllum tenax-Vaccinium scoparium	106	16

Table 14 Continued.

Vegetation Complex (Class)	Percent Area (Acres)	Description and Composition by Forest Habitat Types or by Ecological Landtypes	Occurrence	Percent Occurrence (Composition)*
Complex X: (Continued)		750 Abies lasiocarpa/Calamagrostis rubescens	27	4
		690 Abies lasiocarpa/Xerophyllum tenax	18	3
		820 Abies lasiocarpa(Pinus albicaulis)/ Vaccinium scoparium	14	2
		650 Abies lasiocarpa/Calamagrostis canadensis	11	2
		780 Abies lasiocarpa/Arnica cordifolia	8	1
		360 Pseudotsuga menziesii/Juniperus communis	7	1
		320 Pseudotsuga menziesii/Calamagrostis rubescens	7	1
		Total	655	100
Complex XI: TEMPERATE PARKLAND	6.03	Climax Vegetation: Festuca spp., Abies lasiocarpa, Picea spp., Pseudotsuga menziesii, Pinus contorta		
		Xeric to mesic seral forest stages (burns)	57	53
		SCREE	26	24
		Xeric grass-shrublands	24	24
		Total	107	100
Complex XII: CAREX-SALIX MARSH	.03	Carex spp., Betula glandulosa, Salix spp.	-	-

Note: For botanical details of the temperate ecological landtypes, See Table 4, Section I, and for the forest habitat types, See Pfister et al. (1977)

Summary Statistics of Rock and Vegetation Complexes for the Third Generation Map

Area statistics of the rock and vegetation complexes for the third generation map were quite different from those for the second generation map. This resulted from refinement of the vegetation complexes employing altitude zoning. For example, the Mixed Coniferous Forest of the subalpine and temperate zones represented 48% of the study area on the second generation map (Fig. 28 and Table 13). For the third generation map, that forest theme was divided into 2 forest complexes by employing altitude zoning; the Mesic Abies Lasiocarpa/Pinus Albicaulis Forest Complex of the subalpine zone representing 20% of the study area, and the Mixed Coniferous Forest Complex of the temperate zone representing 27% of the study area (Table 15). Additional area changes will be discussed later in the text.

General Description of the Subalpine Forest Complexes

Forest types above 7000 feet (2134m) elevation in western Montana commonly contain *Pinus albicaulis*. This species is a major component of the following habitat types: *Abies lasiocarpa*/*Luzula hitchcockii*; *Vaccinium scoparium* and *Menziesia ferruginea* phases (831 and 832), *Abies*

Table 15 Summary of area statistics for vegetation complexes of the third generation map of Scapegoat.

Complexes	Area: Pixels	Acres	Hectares *	Percent
Alpine Meadow	3487	3905	1580	7.88
Vegetated Rock	2567	2875	1163	5.81
Bare Rock I	2053	2299	930	4.64
Bare Rock II	1551	1737	703	3.51
Xeric Pinus Albicaulis	3541	3966	1604	8.01
Mesic Abies Lasiocarpa/ Pinus Albicaulis Forest	8959	10034	4058	20.25
Subalpine Parkland	3693	4136	1673	8.35
Xeric Abies Lasiocarpa/ Pseudotsuga Menziesii Forest	2887	3233	1308	6.53
Mixed Coniferous Temperate Forest	11951	13385	5414	27.01
Temperate Parkland	2663	2983	1206	6.03
Carex-Salix Marsh	13	15	6	.03
Equisetum Seepage	107	120	48	.25
SCREE	679	760	308	1.54
Unclassified	102	115	46	.23
Total	44253	49563	20047	100.07

* Metric conversion = .40448

Fig. 29 Third generation computer map of the vegetation complexes in the Scapegoat Study Area. To interpret the map, first refer to the color encoded legends, the area statistics, and then see Fig. 13 for altitudinal zonation. For botanical detail and for listings of grizzly bear food plants associated with each complex, see Tables 14 and 45. Specific elements of grizzly bear habitat can be evaluated by relating the size and distribution of the vegetation complexes shown on the map to rating indices, Table 44.

Area Statistics

Vegetation Complexes	Percent Area
Alpine Meadow	7.88
Vegetated Rock	5.81
Rock I - Limestone	4.64
Rock II - Shaded talus slopes and argillite	3.51
Xeric Pinus Albicaulis	8.01
Mesic Abies Lasiocarpa/Pinus Albicaulis Forest	20.25
Subalpine Parkland	8.35
Xeric Abies Lasiocarpa/ Pseudotsuga Menziesii Forest	6.53
Mixed Coniferous Forest	27.01
Temperate Parkland	6.03
Carex-Salix Marsh	.03
Equisetum Seepage	.25
SCREE	1.54
Unclassified	.23
TOTAL	100.07

Note: The color key accompanying Fig. 29 can be used to interpret Figs. 42 and 43 which occur later in the text.

KEY TO THIRD GENERATION MAP

COLOR		VEGETATION COMPLEX
LIGHT BLUE	I	ALPINE MEADOW
GOLD	II	VEGETATED ROCK
PINK	III	BARE ROCK I
RED	IV	BARE ROCK II
LIGHT GREEN	V	XERIC PINUS ALBICAULIS FOREST
DARK GREEN	VI	MESIC ABIES LASIOCARPA/PINUS ALBICAULIS FORES
GRAY	VII	SUBALPINE PARKLAND
CREAM	VIII	EQUISETUM SEEPAGE
DARK PURPLE	IX A IX B	XERIC ABIES LASIOCARPA FOREST XERIC PSEUDOTSUGA MENZIESII FOREST
VIOLET	X	MIXED CONIFEROUS TEMPERATE FOREST
GRAY-BLUE	XI	TEMPERATE PARKLAND
GOLD-BROWN	XII	CAREX-SALIX MARSH
LIGHT BROWN	XIII	SCREE

lasiocarpa (Pinus albicaulis)/ Vaccinium scoparium (820), and Pinus albicaulis-Abies lasiocarpa (850). Other minor habitat types are the Pinus albicaulis where P. albicaulis occurs in relatively pure stands, and the Larix lyallii-Abies lasiocarpa. These latter two represent the extremes of habitat types, pure P. albicaulis occurring on xeric, high elevation, southerly aspects of high light intensity; while Larix lyallii also occurs at high elevations but on moist northerly aspects of relatively low light intensity. The general climatic climax for the Scapegoat Study Area above 7000 feet (2134m) elevation is the Abies lasiocarpa forest habitat series. Pfister et al. (1977) calls Pinus albicaulis a long-lived seral dominant on all but the moist sites in this forest series of the subalpine zone. The abundance of P. albicaulis in relation to Abies lasiocarpa appears related to xeric site conditions, the pine being most abundant on dry, east to south aspects. Sites on moist, northerly slopes favored A. lasiocarpa with an undergrowth of Menziesia ferruginea. On these sites, P. albicaulis was less common and even nearly excluded.

The Abies lasiocarpa (P. albicaulis)/Vaccinium scoparium habitat type is considered the east side counterpart to the west side Abies lasiocarpa/Luzula hitchcockii

habitat type, Vaccinium scoparium phase (Pfister et al. 1977). In the Scapegoat area, and throughout much of the Bob Marshall Wilderness where calcareous soils are present, the indicator species Luzula hitchcockii is absent; the Abies lasiocarpa (Pinus albicaulis)/Vaccinium scoparium habitat type occupies and dominates the limestone soils in the subalpine zone. Species abundance and occurrence is quite similar for the two habitat types. Generally, Xerophyllum tenax is a common undergrowth plant where L. hitchcockii is the major indicator species. It is less common on the calcareous subalpine soils but still may exhibit rather high coverages locally. Vaccinium scoparium is common on both calcareous and non-calcareous sites but Vaccinium globulare is much more so on the non-limestone substrate. On the xeric limestone sites, plants normally occurring at lower elevation extend their altitudinal range to take in part of this Abies lasiocarpa (Pinus albicaulis)/Vaccinium scoparium habitat type. Plants such as Festuca idahoensis, Calamagrostis rubescens, and Carex geyeri may occur with P. albicaulis. These undergrowth plants usually occur on steeper, southerly aspects with light-canopied timber stands. Perhaps the most diagnostic ecological feature distinguishing the

Abies lasiocarpa/*Luzula hitchcockii* habitat type *Vaccinium scoparium* phase from *Abies lasiocarpa*(*Pinus albicaulis*)/ *Vaccinium scoparium* is the much greater total density of plant cover both overstory and undergrowth in the forests composed largely of the former. This easily observable ecological feature was used to broadly differentiate the xeric and mesic subalpine forests.

The two forest groupings yielded two distinct spectral signatures. Gray level values for the Xeric Pinus Albicaulis Forest Complex ranged from 16 to 33 μm in band 7 and 10 to 16 μm in band 5. Gray level values for the Mesic Abies Lasiocarpa-Pinus Albicaulis Forest Complex ranged from 5 to 15 μm in band 7 and 6 to 18 μm in band 5 (Fig. 10). In both groupings *P. albicaulis* was a major component of the forests with *Abies lasiocarpa* the dominant species. These two subalpine forest complexes, represented by unique signatures were sampled and described by habitat types.

Xeric Pinus Albicaulis Forest Complex

The Xeric Pinus Albicaulis Forest Complex consisted of the forest habitat types between 7000-7600 feet (2134-2316m), predominantly on E, SE, S, and SW exposures with

Abies lasiocarpa dominant and _Pinus albicaulis_ a major component. _Vaccinium scoparium_ was usually common. On xeric ridges and slopes _P. albicaulis_ dominated the forest stands, but it was usually found in nearly pure stands only in the _Pinus albicaulis_ habitat type (870). In eight habitat types, _P. albicaulis_ was normally found in mixed stands with _Abies lasiocarpa_ and _Picea engelmannii_ or _Pinus contorta_ and at about the 7000 foot (2134m) level with _Pseudotsuga menziesii_. Because of the mixed nature of the _P. albicaulis_ forest stands, it was not technically feasible to develop a signature that would display _Pinus albicaulis_ alone or distinguish between habitat types in which it occurred. However, ground truth data showed that the xeric, light to open canopied forests on easterly and southerly slopes above 7000 feet (2134m) were largely _P. albicaulis_ stands. Accordingly, I developed a signature that displayed this forest complex. Ground sampling showed that on E, SE, S, and SW exposures the _Abies lasiocarpa/ Luzula hitchcockii_ habitat type, _Vaccinium scoparium_ phase represented 42% of the forest cover in a random series of 173 1/5 acre plots. The ground sampling also showed that _Abies lasiocarpa/Luzula hitchcockii-Vaccinium scoparium_,

Pinus albicaulis-Abies lasiocarpa, and A. lasiocarpa (Pinus albicaulis)/Vaccinium scoparium habitat types composed 80% of this forest complex. Nine habitat types representing 89% of the total forest cover of the Xeric Pinus Albicaulis Forest Complex were recorded as being on xeric sample sites and 11% on mesic ones (Table 16). Thus, there was no doubt that the complex was ecologically xeric and that P. albicaulis was a major constituent. A detailed composition breakdown of the Xeric Pinus Albicaulis Forest Complex is presented in Table 16.

To further check the composition of the Xeric Pinus Albicaulis Forest Complex, I calculated the occurrence of forest habitat types for the complex using the grid square point-intercept technique described under METHODS and compared the results with those from the field sample plots (Table 17). Percentages of the three major habitat types (831, 850, and 820) combined are similar, showing 80% for the field plot method and 78% for the grid square computations. I concluded that the Xeric Pinus Albicaulis Forest Complex is predominantly composed of three habitat types in which Abies lasiocarpa is the dominant species, Pinus albicaulis common and Vaccinium scoparium a predominant undergrowth species.

Table 16. Vegetation Description of the Xeric Pinus Albicaulis Forest Complex by forest habitat types.

Habitat Types	Occurrence of Habitat Types	Percent Composition by Habitat Types	Percent Occurrence of Xeric Habitat Types
831 Abies lasiocarpa/Luzula hitchcockii-Vaccinium scoparium	73	42	42
850 Pinus albicaulis-Abies lasiocarpa	50	30	30
820 Abies lasiocarpa(Pinus albicaulis)/Vaccinium scoparium	14	8	8
832 Abies lasiocarpa/Luzula hitchcockii-Menziesia ferruginea	7	4	
860 Larix lyallii-Abies lasiocarpa	10	6	
870 Pinus albicaulis	4	2	2
670 Abies lasiocarpa/Menziesia ferruginea	3	2	
692 Abies lasiocarpa/Xerophyllum tenax-Vaccinium scoparium	3	2	2
691 Abies lasiocarpa/Xerophyllum tenax-Vaccinium globulare	3	2	2
690 Abies lasiocarpa/Xerophyllum tenax	2	1	1
323 Pseudotsuga menziesii/Calamagrostis rubescens	1	1	1
650 Abies lasiocarpa/Calamagrostis canadensis	1	1	
330 Pseudotsuga menziesii/Carex geyeri	2	1	1
Total	173	102	89

Table 17. Comparison of the Field Plot Versus the Grid Square Method for Determining the Vegetation Description of the Xeric Pinus Albicaulis Forest Complex.

Description and Composition by Habitat Types	Percent Composition by Habitat Types: Field Plot Method (173 plots)	Percent Composition by Habitat Types: Grid Square Method (321 grid samples)
Climax Vegetation: Abies lasiocarpa		
831 Abies lasiocarpa/Luzula hitchcockii-Vaccinium scoparium	42	42
850 Pinus albicaulis-Abies lasiocarpa	30	14
820 Abies lasiocarpa(Pinus albicaulis)/Vaccinium scoparium	8	22
832 Abies lasiocarpa/Luzula hitchcockii-Menziesia ferruginea	4	5
860 Larix lyallii-Abies lasiocarpa	6	3
870 Pinus albicaulis	2	0
692 Abies lasiocarpa/Xerophyllum tenax-Vaccinium scoparium	2	4
690 Abies lasiocarpa/Xerophyllum tenax	1	0
691 Abies lasiocarpa/Xerophyllum tenax-Vaccinium globulare	2	3
670 Abies lasiocarpa/Menziesia ferruginea	2	0
330 Pseudotsuga menziesii/Carex geyeri	1	0
323 Pseudotsuga menziesii/Calamagrostis rubescens	1	0
650 Abies lasiocarpa/Calamagrostis canadensis	1	0
010 SCREE	0	7
Total	102	100

Mesic Abies Lasiocarpa-Pinus Albicaulis Forest Complex

The Mesic Abies Lasiocarpa-Pinus Albicaulis Forest Complex also consisted of forest habitat types between 7000 - 7600 feet (2134 - 2316m), but predominantly on NE, N, NW, and W exposures. Sites were primarily mesic and forest canopy medium to heavy. This complex supported percentages of forest habitat types as shown in Table 14. It is ecologically similar to the Xeric Pinus Albicaulis Forest Complex; however, the canopy cover of the mesic complex was much denser. For example, the Abies lasiocarpa/Luzula hitchcockii habitat type, Vaccinium scoparium phase (831) was predominant in both complexes comprising 42% in the xeric complex and 37% in the mesic; but exhibited marked differences in stand density. Moreover, the high percentage of the Abies lasiocarpa/Luzula hitchcockii habitat type, Menziesia ferruginea phase (832) and the low percentage of the Pinus albicaulis-Abies lasiocarpa habitat type (850) was a constant feature distinguishing the mesic complex from the xeric one. Vaccinium scoparium and Menziesia ferruginea were common undergrowth plants. Habitat types 831, 832, and 820 together composed 68% of the vegetation of this complex (Table 14); whereas in the Xeric Pinus Albicaulis Forest Complex, types 831,

850, and 820 formed 80% of the vegetation (Table 16).

General Description of the Temperate Forest Complexes

Below 7000 feet (2134m) in elevation the forests displayed a characteristic change in vegetation components. This change in vegetation served as an elevational demarcation between the subalpine and temperate forests.

In contrast to the subalpine forest, the temperate forest did not support appreciable amounts of *Pinus albicaulis*; *Pseudotsuga menziesii* was an important overstory component. Forest habitat types of this series (Pfister et al. 1977) dominated much of the lower elevations and the xeric sites at higher elevations. In addition, the subalpine forest indicator forb, *Luzula hitchcockii*, was absent from the temperate forest. Much of the undergrowth vegetation was similar to that of the subalpine forest types, but some species were zone specific.

Two phases of the *Abies lasiocarpa*/*Xerophyllum tenax* forest habitat type dominated much of the temperate forest in the Scapegoat Study Area. The *Vaccinium globulare* phase was characterized by *V. globulare* and *V. scoparium* as well as by an abundance of *Xerophyllum tenax*. *Abies lasiocarpa*

was the dominant component of the overstory with varying amounts of _Pseudotsuga menziesii_ and _Pinus contorta_. At lower elevations _Pseudotsuga menziesii_/_Calamagrostis rubescens_ was a major forest type. On those situations _P. menziesii_ was the dominant overstory component and _A. lasiocarpa_ was absent. Much of the undergrowth consisted of _Calamagrostis rubescens_ and other graminoids.

On moist sites, _Abies lasiocarpa_/_Menziesia ferruginea_ was a predominant habitat type. _Abies lasiocarpa_/_Xerophyllum tenax_ forest habitat type, _Vaccinium globulare_ and _V. scoparium_ phases also occurred on mesic sites.

As in the subalpine zone the xeric and mesic forest groups displayed differences in canopy density and therefore, spectrally distinct signatures.

Xeric Abies Lasiocarpa-Pseudotsuga Menziesii Forest Complex

Forests of the Xeric Abies Lasiocarpa-Pseudotsuga Menziesii Forest Complex could not be further differentiated by spectral reflectance or by altitude zoning. However, they could be separated into subcomplexes by differences in habitat types. The two subcomplexes were termed the Xeric Abies Lasiocarpa Forest Subcomplex and the Xeric Pseudotsuga Menziesii Forest Subcomplex. For

a vegetation description of each subcomplex, refer to Table 14.

Mixed Coniferous Forest Complex

The Mixed Coniferous Forest, the single largest complex, accounted for 27% of the Scapegoat area (Table 14). This complex represented the moist site forests within the temperate zone. *Abies lasiocarpa/Menziesia ferruginea* was the most common habitat type and comprised 43% of the forest composition (Table 14). Characteristic of that moist habitat type, *Menziesia ferruginea* represented 17.1% of the undergrowth in the complex. Another major forest type in this complex was the *Abies lasiocarpa/Xerophyllum tenax* of both the *Vaccinium globulare* and *V. scoparium* phases.

A detailed description of the forest habitat types that comprised the Mixed Coniferous Forest Complex is presented in Table 14.

Description of Vegetation Complexes by Undergrowth Species

I described each vegetation complex in greater botanical detail. Percent vegetative cover and percent occurrence of undergrowth species were sampled within the

ecologically similar land-vegetation units and forest habitat types.

Vegetation Descriptions of the Alpine Zone Complexes

Alpine Meadow Complex

The signatures for the Alpine Meadow Complex ranged from 16 to 35 μm in band 7 and 17 to 30 μm in band 5. It represented spectral values from a composite of 5 ecological land units.

The vegetation composition of the Alpine Meadow Complex is shown in Tables 18 and 19. Greater botanical detail is presented in Tables 29 and 30 of Section I Appendix. *Festuca idahoensis* and various species of *Carex* were the predominant species. Together they comprised 37% of the plant cover. Although cushion plants and mat-formers were conspicuous elements of the alpine vegetation, only *Dryas octopetala*, *Phlox pulvinata*, and *Arctostaphylos uva-ursi* contributed significant percentages to total plant cover. *Thalictrum occidentale* and *Luzula hitchcockii* were present in the krummholz.

Frequence of occurrence of *Carex* spp., *Festuca idahoensis*, *Phlox pulvinata*, and *Dryas octopetala* in the sample plots (Table 19) also reflected the dominance of

Table 18 Percent vegetative composition of plant species in the Alpine Meadow Complex (94 plots, 108,664 square miles).

Alpine Vegetation	Total % Vegetative Cover	Percent Vegetation
Carex spp.	1445	20.9
Festuca idahoensis	1110	16.0
Dryas octopetala	460	6.6
Phlox pulvinata	360	5.2
Arctostaphylos uva-ursi	345	5.0
Thalictrum occidentale	330	4.8
Luzula hitchcockii	270	3.9
Gramineae	190	2.7
Salix arctica	170	2.5
Ranunculus eschscholtzii	170	2.5
Oxytropis campetris	145	2.1
Valeriana spp.	140	2.0
Potentilla fruiticosa	125	1.8
Hedysarum spp.	120	1.7
Potentilla diversifolia	110	1.6
Vaccinium scoparium	105	1.5
Anemone spp.	105	1.5
Polygonum spp.	95	1.4
Caltha leptosepala	95	1.4
Gentiana calycosa	85	1.2
Erythronium grandiflorum	85	1.2
Trace forbs	85	1.2
Achillea millefolium	80	1.2
Erigeron spp.	80	1.2
Antennaria spp.	75	1.1
Astragalus spp.	75	1.1
Eritrichium nanum	65	.9
Juncus parryi	55	.8
Arnica spp.	45	.6
Senecio spp.	45	.6
Pedicularis spp.	40	.6
Lomatium spp.	40	.6
Arenaria spp.	25	.4
Arabis nuttallii	25	.4
Douglasia montana	20	.3
Solidago multiradiata	20	.3
Dodecatheon spp.	15	.2
Besseya wyomingensis	10	.1
Veronica sp.	10	.1
Cirsium scariosum	10	.1
Ribes spp.	10	.1
Phyllodoce spp.	5	.1
Penstemon ellipticus	5	.1
Juniperus communis	5	.1
Delphinium bicolor	5	.1
Lloydia cerotina	5	.1
Cardamine rupicola	5	.1
Claytonia lanceolata	5	.1
Physaria didymocarpa	5	.1
Total	6930	100.2
Abies lasiocarpa	1120	72.5
Pinus albicaulis	365	23.6
Picea engelmannii	60	3.9
Total	1545	100.0

Table 19 Percent occurrence of plant species in the Alpine Meadow Complex (94 plots, 108,664 square feet)

Alpine Vegetation	No. Plots where plant occurred	% Occurrence
Carex spp.	54	57.4
Festuca idahoensis	36	38.3
Phlox pulvinata	22	23.4
Thalictrum occidentale	19	20.2
Dryas octopetala	17	18.1
Hedysarum spp.	17	18.1
Potentilla diversifolia	17	18.1
Potentilla fruiticosa	16	17.0
Gramineae	15	16.0
Polygonum spp.	14	14.9
Luzula hitchcockii	13	13.8
Oxytropis campestris	13	13.8
Valeriana spp.	13	13.8
Achillea millefolium	12	12.8
Ranunculus eschscholtzii	11	11.7
Arctostaphylos uva-ursi	10	10.6
Gentiana calycosa	10	10.6
Erigeron spp.	10	10.6
Anemone spp.	9	9.6
Salix arctica	7	7.4
Vaccinium scoparium	7	7.4
Arnica spp.	7	7.4
Antennaria spp.	6	6.4
Pedicularis spp.	6	6.4
Caltha leptosepala	5	5.3
Eritrichium nanum	5	5.3
Senecio spp.	5	5.3
Lomatium spp.	5	5.3
Astragalus spp.	4	4.3
Juncus parryi	4	4.3
Arenaria spp.	4	4.3
Trace forbs	4	4.3
Dodecatheon spp.	3	3.2
Erythronium grandiflorum	2	2.1
Arabis nuttallii	2	2.1
Douglasia montana	1	1.1
Solidago multiradiata	1	1.1
Besseya wyomingensis	1	1.1
Veronica spp.	1	1.1
Circium scariosum	1	1.1
Ribes spp.	1	1.1
Phyllodoce spp.	1	1.1
Penstemon ellipticus	1	1.1
Juniperus communis	1	1.1
Delphinium bicolor	1	1.1
Lloydia serotina	1	1.1
Cardamine rupicola	1	1.1
Claytonia lanceolata	1	1.1
Physaria didymocarpa	1	1.1

these plants in the Alpine Meadow Complex.

Vegetated Rock Complex

The signature for the Vegetated Rock Complex ranged from 16 to 24 μm in band 7 and 31 to 65 μm in band 5. Like the Alpine Meadow Complex, it too was a composite of the vegetation characteristic of a number of alpine ecological land units, Table 20.

The botanical composition of the complex is shown in Table 20 (Tables 12 and 13, Section I Appendix); it closely resembled the Alpine Meadow Complex, but differed in having fewer species that comprised 5% or more of the total cover. Dryas octopetala predominanted; this predominance distinguished the complex. Both Carex spp. and Festuca idahoensis contributed high percentages of the plant cover, similar to what was observed in the Alpine Meadow Complex. The lower representation of Luzula hitchcockii and the absence of Thalictrum occidentale reflected, however, a relative decline in krummholz. When krummholz did occur, it was mostly mat-forming with little or no undergrowth. Claytonia megarhiza and Cardimine rupicola were restricted to the talus slopes and boulder fields of the Vegetated Rock Complex and were considered indicator species.

Data on frequency of occurrence supported the dom-

Table 20 Percent vegetative composition of plant species in the Vegetated Rock Complex (65 plots, 75,140 square feet).

Alpine Vegetation	Total % Vegetative Cover	Percent Vegetation
Dryas octopetala	565	22.0
Carex spp.	445	17.3
Festuca idahoensis	320	12.5
Arctostaphylos uva-ursi	160	6.2
Salix spp.	160	6.2
Phyllodoce spp.	120	4.7
Juncus parryi	100	3.9
Gramineae	95	3.7
Trace forbs	75	2.9
Potentilla fruiticosa	70	2.7
Phlox pulvinata	70	2.7
Antennaria spp.	65	2.5
Gentiana calycosa	35	1.4
Claytonia megarhiza	30	1.2
Potentilla diversifolia	30	1.2
Ranunculus eschscholtzii	25	1.0
Hedysarum spp.	25	1.0
Lomatium cous	25	1.0
Luzula hitchcockii	20	.8
Arabis spp.	20	.8
Achillea millefolium	20	.8
Arenaria spp.	15	.6
Anemone spp.	15	.6
Cardamine rupicola	15	.6
Penstemon ellipticus	10	.4
Claytonia lanceolata	5	.2
Silene acaulis	5	.2
Fragaria virginiana	5	.2
Besseya wyomingensis	5	.2
Erigeron spp.	5	.2
Erythronium grandiflorum	5	.2
Pedicularis spp.	5	.2
Valeriana spp.	5	.2
Total	2570	100.3
Abies lasiocarpa	245	68.1
Pinus albicaulis	105	29.2
Picea engelmannii	10	2.8
Total	360	100.1

inant positions of Carex spp. Dryas octopetala, and Festuca idahoensis in the Vegetated Rock Complex (Table 21). The most visible characteristic, distinguishing the Alpine Meadow from the Vegetated Rock Complex, was not species composition; but the great difference in total vegetation cover (Tables 14 and 15, Section I Appendix). A paucity of vegetation ground-cover with exposed rock surfaces yielded the unique signature for the complex.

Rock Complexes

I extracted three signatures for the non-vegetated portions of the study area representing limestone rock, argillite, and rock in deep shadow (Fig. 10). Two of these, argillite and rock in deep shadow, were combined for mapping purposes. These landforms existed as both parent rock and talus. The light-gray-colored bare limestone reflected a range of solar energy, gray levels 25 to 41 μm in band 5 and 31 to 127 μm in band 7, that produced an overall spectral reflectance value separable from that of the russet-colored argillite. Rock in deep shadow was invariably steep talus slopes directly beneath precipitous cliffs and headwalls. Some of the sheer

Table 21 Percent occurrence of plant species in the Vegetated Rock Complex (65 plots, 75,140 square feet)

Alpine Vegetation	No. Plots Where Plant Occurred	% Occurrence
Carex spp.	29	44.6
Dryas octopetala	26	40.0
Festuca idahoensis	13	20.0
Trace forbs	12	18.5
Arctostaphylos uva-ursi	10	15.4
Gramineae	8	12.3
Potentilla fruiticosa	6	9.2
Phlox pulvinata	6	9.2
Juncus parryi	5	7.7
Lomatium cous	5	7.7
Phyllodoce spp.	4	6.2
Salix spp.	4	6.2
Antennaria spp.	3	4.6
Gentiana calycosa	3	4.6
Claytonia megarhiza	3	4.6
Potentilla diversifolia	3	4.6
Hedysarum spp.	3	4.6
Achillea millefolium	3	4.6
Ranunculus eschscholtzii	2	3.1
Anemone spp.	2	3.1
Cardamine rupicola	2	3.1
Luzula hitchcockii	1	1.5
Arabis spp.	1	1.5
Arenaria spp.	1	1.5
Penstemon ellipticus	1	1.5
Claytonia lanceolata	1	1.5
Silene acaulis	1	1.5
Fragaria virginiana	1	1.5
Besseya wyomingensis	1	1.5
Erigeron spp.	1	1.5
Erythronium grandiflorum	1	1.5
Pedicularis spp.	1	1.5
Valeriana spp.	1	1.5

headwalls dropped 1000 to 1500 feet (305 to 457m), and cast dark shadows which yielded the unique signature shown in Fig. 6. The presence of both argillite and limestone-derived soils complicated the plant ecology, and thus, the associated vegetative patterns. This in turn, added to the difficulty of habitat typing and computer mapping the study area.

Descriptions of Vegetation Undergrowth in the Subalpine Zone Complexes

The landtypes of the subalpine zone grass-shrublands were consolidated to form a complex termed the Subalpine Parkland Complex. This included vegetation of the Seral Forest Stages (Burns), Wet Forb-Grasslands, Dry Forb-Grasslands, Snowslides, and Ridgetop Glades. Trees were scattered or absent with arboreal canopy cover ranging from 0 through 15%. Gray level values for this complex are shown in Fig. 24. As explained earlier, the signature was so similar (Fig. 11) to that of the Alpine Meadow Complex, the two had to be differentiated using signature polygons at the 7600 foot (2316m) contour (Figs. 13 and 29).

The subalpine forest habitat types were grouped according to spectral values to form 2 forest complexes.

Gray level values are shown in Fig. 24.

The undergrowth species for the Subalpine Parkland Complex and the Xeric Pinus Albicaulis and Mesic Abies Lasiocarpa/Pinus Albicaulis Complexes were sampled and used as a basis for describing them.

Undergrowth of the Subalpine Parkland Complex

The plant cover of the Subalpine Parkland Complex showed a predominance of *Carex geyeri* and *Xerophyllum tenax*, with *Festuca idahoensis* and *Senecio triangularis* well-represented (Tables 22 and 23). The complex supported a large number of grass, sedge, and forb species.

Percent occurrence data also indicated that *Carex geyeri*, *Xerophyllum tenax*, and *Festuca idahoensis* were major components of the flora (Table 23).

Forbs occurring at less than the 5% level of cover characterized many of the plots. They composed 8.3% of the total cover. Similarly, the percent occurrence of these forbs by plots was extremely high. This situation reflected the low density - broad distribution of forbs throughout the complex. In other words, the density distribution of many forb species was 5% or more of the total vegetative cover within a given plot; yet these same forbs also occurred in numerous plots below the 5%

Table 22 Summary of percent vegetative cover in five ecological landtypes of the Subalpine Parkland Complex. (123 plots, 142,188 square feet.)

Vegetation	Total Percent Vegetation Cover	Percent Vegetation
Carex spp. (geyeri predominant)	1170	13.1
Xerophyllum tenax	1080	12.1
Trace forbs*	740	8.3
Festuca idahoensis	685	7.7
Gramineae**	535	6.0
Senecio triangularis	480	5.4
Lupinus argenteus	330	3.7
Vaccinium scoparium	285	3.2
Thalictrum occidentale	275	3.1
Calamagrostis canadensis	195	2.2
Calamagrostis rubescens	170	1.9
Fragaria virginiana	135	1.5
Astragalus bourgovii	130	1.4
Menziesia ferruginea	130	1.4
Allium schoenoprasum	125	1.4
Equisetum arvense	105	1.2
Salix spp.	105	1.2
Heracleum lanatum	95	1.1
Antennaria spp.	95	1.1
Erythronium grandiflorum	90	1.0
Bryophyta	80	.9
Osmorhiza occidentalis	80	.9
Anemone parviflora	80	.9
Aster sp.	75	.8
Claytonia lanceolata	70	.8
Vaccinium globulare	50	.6
Potentilla diversifolia	50	.6
Lomatium spp.	50	.6
Shepherdia canadensis	45	.5
Astragalus vexilliflexus	45	.5
Arnica cordifolia	45	.5
Achillea millefolium	45	.5
Phyllodoce empetriformis	40	.4
Arenaria spp.	40	.4
Anemone multifida	35	.4
Senecio megacephalus	35	.4
Oxytropis spp.	35	.4
Festuca scabrella	30	.3
Polygonum bistortoides	30	.3
Geranium spp.	30	.3
Penstemon spp.	30	.3
Juncus spp.	30	.3
Sibbaldia procumbens	25	.3
Hackelia micrantha	25	.3
Veronica sp.	25	.3
Hackelia sp.	25	.3
Parnassia fimbriata	25	.3
Luzula hitchcockii	20	.2
Zigadenus elegans	20	.2
Agropyron spp.	20	.2
Sium suave	20	.2
Agastache urticifolia	20	.2
Veratrum sp.	20	.2
Eriogonum spp.	20	.2
Lomatium dissectum	20	.2
Erigeron peregrinus	20	.2
Antennaria umbrinella	15	.2
Juncus parryi	15	.2
Senecio spp.	15	.2
Balsamorhiza sagittata	15	.2

Vegetation	Total Percent Vegetation Cover	Percent Vegetation
Pedicularis groenlandica	15	.2
Taraxacum officinale	15	.2
Galium spp.	15	.2
Pedicularis spp.	15	.2
Hedysarum occidentale	15	.2
Poa spp.	15	.2
Potentilla fruiticosa	15	.2
Solidago spp.	10	.1
Phleum pratense	10	.1
Bromus sp.	10	.1
Vaccinium myrtillus	10	.1
Cicuta douglasii	10	.1
Gentiana calycosa	10	.1
Vicia villosa	10	.1
Lonicera involucrata	10	.1
Geranium viscosissimum	10	.1
Penstemon ellipticus	10	.1
Solidago multiradiata	10	.1
Melica spectabilis	10	.1
Ranunculus eschscholtzii	10	.1
Arnica spp.	10	.1
Erigeron compositus	10	.1
Pedicularis contorta	5	.1
Amelanchier alnifolia	5	.1
Anaphalis margaritacea	5	.1
Artemisia ludoviciana	5	.1
Castilleja spp.	5	.1
Galium boreale	5	.1
Matricaria matricarioides	5	.1
Cirsium scariosum	5	.1
Rubus parviflorus	5	.1
Hedysarum sulphurescens	5	.1
Haplopappus lyallii	5	.1
Dodecatheon spp.	5	.1
Habenaria dilatata	5	.1
Frasera speciosa	5	.1
Senecio canus	5	.1
Arctostaphylos uva-ursi	5	.1
Spiraea betulifolia	5	.1
Saxifraga spp.	5	.1
Caltha leptosepala	5	.1
Cerastium arvense	5	.1
Sedum spp.	5	.1
Veratrum veride	5	.1
Arnica longifolia	5	.1
Valariana sitchensis	5	.1
Juniperus communis	5	.1
Trace shrubs and trees ***	150	1.7
Pinus albicaulis reproduction	5	.1
Picea engelmannii reproduction	5	.1
Total	8910	101.0

*Includes identified forbs that occurred at less than the 5% level of cover.
**Gramineae includes grasses that could not be identified when the plots were taken because of immature stages. These were later keyed by Klaus Lockschenwitz at the University of Montana herbarium and appear in the species lists.
***Includes trees and shrubs that occurred at less than the 5% level of cover.

Table 23 Summary of percent occurrence in five ecological landtypes of the Subalpine Parkland Complex. (123 plots, 142,188 square feet.)

Vegetation	No. Plots Where Plants Occurred	Percent Occurrence
Trace forbs *	77	62.6
Carex spp. (geyeri predominant)	68	55.3
Xerophyllum tenax	35	28.5
Gramineae * *	34	27.6
Festuca idahoensis	31	25.2
Thalictrum occidentale	19	15.4
Fragaria virginiana	19	15.4
Calamagrostis rubescens	18	14.6
Lupinus argenteus	18	14.6
Senecio triangularis	16	13.0
Vaccinium scoparium	14	11.4
Erythronium grandiflorum	9	7.3
Lomatium spp.	9	7.3
Heracleum lanatum	8	6.5
Aster sp.	8	6.5
Potentilla diversifolia	8	6.5
Shepherdia canadensis	8	6.5
Arnica cordifolia	7	5.7
Achillea millefolium	7	5.7
Antennaria spp.	6	4.9
Polygonum bistortoides	6	4.9
Calamagrostis canadensis	5	4.1
Salix spp.	5	4.1
Bryophyta	5	4.1
Senecio megacephalus	5	4.1
Allium schoenoprasum	5	4.1
Astragalus bourgovii	4	3.3
Equisetum arvense	4	3.3
Anemone parviflora	4	3.3
Anemone multifida	4	3.3
Hackelia sp.	4	3.3
Parnassia fimbriata	4	3.3
Luzula hitchcockii	4	3.3
Osmorhiza occidentalis	4	3.3
Claytonia lanceolata	3	2.4
Phyllodoce empetriformis	3	2.4
Oxytropis spp.	3	2.4
Festuca scabrella	3	2.4
Juncus spp.	3	2.4
Hackelia micrantha	3	2.4
Eriogonum spp.	3	2.4
Senecio spp.	3	2.4
Pedicularis groenlandica	3	2.4
Galium spp.	3	2.4
Hedysarum occidentale	3	2.4
Poa spp.	3	2.4
Potentilla fruiticosa	3	2.4
Menziesia ferruginea	2	1.6
Vaccinium globulare	2	1.6
Arenaria spp.	2	1.6
Geranium spp.	2	1.6
Penstemon spp.	2	1.6
Sibbaldia procumbens	2	1.6
Veronica sp.	2	1.6
Zigadenus elegans	2	1.6
Agastache urticifolia	2	1.6
Lomatium dissectum	2	1.6
Balsamorhiza sagittata	2	1.6
Taraxacum officinale	2	1.6

Vegetation	No. Plots Where Plants Occurred	Percent Occurrence
Pedicularis spp.	2	1.6
Vaccinium myrtillus	2	1.6
Cicuta douglasii	2	1.6
Geranium viscosissimum	2	1.6
Astragalus vexilliflexus	1	.8
Agropyron spp.	1	.8
Sium suave	1	.8
Erigeron peregrinus	1	.8
Antennaria umbrinella	1	.8
Juncus parryi	1	.8
Solidago spp.	1	.8
Phleum pratense	1	.8
Bromus sp.	1	.8
Gentiana calycosa	1	.8
Vicia villosa	1	.8
Lonicera involucrata	1	.8
Penstemon ellipticus	1	.8
Solidago multiradiata	1	.8
Melica spectabilis	1	.8
Ranunculus eschscholtzii	1	.8
Arnica spp.	1	.8
Erigeron compositus	1	.8
Pedicularis contorta	1	.8
Amelanchier alnifolia	1	.8
Anaphalis margaritacea	1	.8
Artemisia ludoviciana	1	.8
Castilleja spp.	1	.8
Galium boreale	1	.8
Matricaria matricarioides	1	.8
Cirsium scariosum	1	.8
Rubus	1	.8
Hedysarum sulphurescens	1	.8
Haplopappus lyallii	1	.8
Dodecatheon spp.	1	.8
Habenaria dilatata	1	.8
Frasera speciosa	1	.8
Senecio canus	1	.8
Arctostaphylos uva-ursi	1	.8
Spiraea betulifolia	1	.8
Saxifraga spp.	1	.8
Caltha leptosepala	1	.8
Cerastium arvense	1	.8
Sedum spp.	1	.8
Veratrum veride	1	.8
Arnica longifolia	1	.8
Valariana sitchensis	1	.8
Juniperus communis	1	.8
Trace shrubs and trees ***	26	21.1
Pinus albicaulis reproduction	1	.8
Picea engelmannii reproduction	1	.8

*Includes identified forbs that occurred at less than the 5% level of cover.
**Gramineae includes grasses that could not be identified when the plots were taken because of immature stages. These were later keyed by Klaus Lockschenwitz at the University of Montana herbarium and appear in the species lists.
***Includes trees and shrubs that occurred at less than the 5% level of cover.

level. When this occurred they were combined and recorded as trace forbs. For greater detail, see Table 2, Section I.

Undergrowth of the Xeric Pinus Albicaulis Forest Complex

Vaccinium scoparium and Xerophyllum tenax were by far the most abundant and widely distributed undergrowth species in the Xeric Pinus Albicaulis Forest Complex. Vaccinium scoparium and Xerophyllum tenax together comprised 73.7% of the undergrowth vegetation and occurred in 86.7 and 63.3% of the samples, respectively (Table 24).

The number and diversity of plant species was not as great in this complex as in the Subalpine Parkland Complex.

Undergrowth of the Mesic Abies Lasiocarpa-Pinus Albicaulis Forest Complex

Like the Xeric Pinus Albicaulis Forest Complex, the Mesic Abies Lasiocarpa/Pinus Albicaulis Forest Complex supported an abundance of Vaccinium scoparium. This shrub represented 28.3% of the vegetation cover and occurred in 80.6% of the sample plots (Table 25). However, a striking difference was the presence of the moist site indicator Menziesia ferruginea. It accounted for 13.1% of the undergrowth with an occurrence of 30.6%.

Table 24 Summary of percent cover and percent occurrence of undergrowth species in the Xeric Pinus Albicaulis Forest Complex of the Subalpine Zone (30 plots).

Vegetation	Total Percent Vegetative Cover	Percent Vegetation	Percent Occurrence
Vaccinium scoparium	680	43.6	86.7
Xerophyllum tenax	470	30.1	63.3
Trace forbs	95	6.1	56.7
Carex geyeri	85	5.4	36.7
Arnica cordifolia	65	4.2	26.7
Luzula hitchcockii	60	3.8	16.7
Juniperus communis	50	3.2	16.7
Thalictrum occidentale	35	2.2	13.3
Shepherdia canadensis	5	.3	3.3
Vaccinium globulare	5	.3	3.3
Valariana sitchensis	5	.3	3.3
Ledum glandulosum	5	.3	3.3
Ribes lacustre	T	T	T
Calamagrostis rubescens	T	T	T
Calamagrostis canadensis	T	T	T
Festuca idahoenis	T	T	T
Heracleum lanatum	T	T	T
Lomatium dissectum	T	T	T
Cirsium scariosum	T	T	T
Fragaria virginiana	T	T	T
Erythronium grandiflorum	T	T	T
Claytonia lanceolata	T	T	T
Total vegetation	1560	99.8	

Table 25 Summary of percent cover and percent occurrence of undergrowth species in the Mesic Abies Lasiocarpa/Pinus Albicaulis Forest Complex of the Subalpine Zone (36 plots).

Vegetation	Total Percent Vegetative Cover	Percent Vegetation	Percent Occurrence
Vaccinium scoparium	1230	28.3	80.6
Xerophyllum tenax	660	15.2	69.4
Menziesia ferruginea	570	13.1	30.6
Arnica cordifolia	510	11.8	58.3
Thalictrum occidentale	445	10.3	41.7
Carex geyeri	330	7.6	47.2
Luzula hitchcockii	220	5.1	33.3
Phyllodoce empetriformis	180	4.1	13.9
Trace forbs	60	1.4	11.1
Ledum glandulosum	50	1.2	11.1
Rhododendron albiflorum	25	.6	5.6
Juniperus communis	20	.5	2.8
Heracleum lanatum	15	.3	5.6
Fragaria virginiana	10	.2	5.6
Vaccinium globulare	5	.1	2.8
Ribes lacustre	5	.1	2.8
Hedysarum occidentale	5	.1	2.8
Total		100.0	

Xerophyllum tenax, *Arnica cordifolia*, *Thalictrum occidentale*, *Carex geyeri*, and *Luzula hitchcockii* each represented more than 5% of the undergrowth (Table 25).

Description of Vegetation Undergrowth in the Temperate Zone Complexes

As in the subalpine zone, the ecological landtypes and forest habitat types of the temperate zone were consolidated into their respective complexes. The vegetation composition based on undergrowth species was established for each complex.

Altitude zoning at the 7000 foot (2134m) contour was employed to differentiate the temperate from the subalpine zone (Fig. 13) with complexes represented in distinct colors (Fig. 29).

Undergrowth of the Temperate Parkland Complex

The Temperate Parkland Complex supported an abundance of graminoids. *Festuca scabrella*, *F. idahoensis*, and *Carex geyeri* were not only the most abundant species, but were also the most widely distributed, occurring in 46.3, 41.5, and 31.7% of the samples, respectively, and providing 16.9, 7.7, and 7.1% of the cover, respectively (Tables 26 and 27).

Other major components of the vegetation were *Salix*

Table 26 Summary of percent vegetative cover in four ecological landtypes of the Temperate Parkland Complex. (41 plots, 47,396 square feet).

Vegetation	Total % Vegetative Cover	Percent Vegetation
Festuca scabrella	670	16.9
Trace forbs	390	9.8
Festuca idahoensis	305	7.7
Carex spp.	280	7.1
Salix spp.	260	6.5
Betula glandulosa	240	6 0
Potentilla fruiticosa	220	5.5
Carex geyeri	195	4.9
Agropyron spicatum	185	4.7
Xerophyllum tenax	165	4.2
Artemisia tridentata	140	3.5
Phleum pratense	135	3.4
Fragaria virginiana	100	2.5
Gramineae	60	1.5
Trace shrubs and trees	60	1.5
Amelanchier alnifolia	55	1.4
Bromus sp.	45	1.1
Deschampsia cespitosa	40	1.0
Lupinus sp.	35	.9
Shepherdia canadensis	30	.8
Spiraea betulifolia	25	.6
Symphoricarpos albus	25	.6
Poa pratensis	25	.6
Arctostaphylos uva-ursi	25	.6
Juniperus scopulorum	25	.6
Epilobium angustifolium	20	.5
Potentilla gracilis	20	.5
Vaccinium scoparium	15	.4
Swertia perennis	15	.4
Danthonia unispicata	15	.4
Juniperus communis	10	.3
Lonicera utahensis	10	.3
Antennaria spp.	10	.3
Smilacena stellata	10	.3
Hieracium gracile	10	.3
Poa spp.	10	.3
Calamagrostis rubescens	10	.3
Acer glabrum	10	.3
Prunus virginiana	10	.3
Arenaria spp.	5	.1
Galium boreale	5	.1
Apocynum sp.	5	.1
Luzula hitchcockii	5	.1
Achillea millefolium	5	.1
Rosa sp.	5	.1
Tragopogon dubius	5	.1
Geum triflorum	5	.1
Trifolium sp.	5	.1
Perideridia gairdneri	5	.1
Phleum alpinum	5	.1
Sedum spp.	5	.1
Total	3,970	100.0

Table 27 Summary of percent occurrence in four ecological landtypes of the Temperate Parkland Complex. (41 plots, 47,396 square feet).

Vegetation	No. Plots Where Plant Occurred	Percent Occurrence
Trace forbs	40	97.6
Festuca scabrella	19	46.3
Festuca idahoensis	17	41.5
Carex spp.	13	31.7
Potentilla fruiticosa	13	31.7
Carex geyeri	10	24.4
Gramineae	9	22.0
Salix spp.	9	22.0
Trace shrubs and trees	8	19.5
Agropyron spicatum	8	19.5
Fragaria virginiana	6	14.6
Betula glandulosa	6	14.6
Xerophyllum tenax	5	12.2
Phleum pratense	5	12.2
Amelanchier alnifolia	4	9.8
Shepherdia canadensis	3	7.3
Artemisia tridentata	3	7.3
Arctostaphylos uva-ursi	3	7.3
Spiraea betulifolia	2	4.9
Bromus sp.	2	4.9
Lupinus sp.	2	4.9
Symphoricarpos albus	2	4.9
Potentilla gracilis	2	4.9
Swertia perennis	2	4.9
Deschampsia cespitosa	2	4.9
Poa pratensis	2	4.9
Danthonia unispicata	2	4.9
Juniperus scopulorum	2	4.9
Vaccinium scoparium	1	2.4
Juniperus communis	1	2.4
Lonicera utahensis	1	2.4
Antennaria spp.	1	2.4
Smilacina stellata	1	2.4
Hieracium gracile	1	2.4
Poa spp.	1	2.4
Arenaria spp.	1	2.4
Gallium boreale	1	2.4
Apocynum sp.	1	2.4
Luzula hitchcockii	1	2.4
Epilobium angustifolium	1	2.4
Achillea millefolium	1	2.4
Calamagrostis rubescens	1	2.4
Rosa sp.	1	2.4
Tragopogon dubius	1	2.4
Geum triflorum	1	2.4
Trifolium sp.	1	2.4
Perideridia gardneri	1	2.4
Phleum alpinum	1	2.4
Acer glabrum	1	2.4
Prunus virginiana	1	2.4
Sedum spp.	1	2.4

spp., Betula glandulosa, and Potentilla fruiticosa.

Undergrowth of the Xeric Abies Lasiocarpa-Pseudotsuga Menziesii Forest Complex

The Xeric Abies Lasiocarpa-Pseudotsuga Menziesii Forest Complex characteristically supported an abundance of Calamagrostis rubescens. While not the most widely distributed species, it was the most abundant, representing 31.6% of the undergrowth cover (Table 28). Both Xerophyllum tenax and Vaccinium scoparium were more widely distributed than C. rubescens, occurring in 57.1 and 54.3% of the samples, respectively; but contributed only 15.5 and 14.8%, respectively, to the vegetation cover (Table 28).

Other undergrowth species each representing more than 5% of the total vegetation were Vaccinium globulare and Carex geyeri.

Undergrowth of the Mixed Coniferous Forest Complex

The Mixed Coniferous Forest Complex represented the moist site forests in the temperate zone. Menziesia ferruginea was characteristic of the moist conditions and represented 17.1% of the undergrowth cover (Table 29). The most abundant and widely distributed undergrowth species was Vaccinium scoparium, contributing 32.5% of the cover

Table 28 Summary of percent cover and percent occurrence of undergrowth species in the Xeric Abies Lasiocarpa/Pseudotsuga Menziesii Forest Complex of the Temperate Zone (35 plots).

Vegetation	Total Percent Vegetative Cover	Percent Vegetation	Percent Occurrence
Calamagrostis rubescens	865	31.6	42.9
Xerophyllum tenax	425	15.5	57.1
Vaccinium scoparium	405	14.8	54.3
Vaccinium globulare	245	8.9	31.4
Carex geyeri	245	8.9	25.7
Trace forbs	145	5.3	71.4
Juniperus communis	60	2.2	11.4
Spiraea betulifolia	55	2.0	20.0
Balsamorhiza sagittata	50	1.8	14.3
Arnica cordifolia	50	1.8	20.0
Agropyron spicatum	35	1.3	11.4
Fragaria virginiana	25	.9	11.4
Thalictrum occidentale	25	.9	8.6
Lupinus argenteus	15	.5	5.7
Symphoricarpos albus	15	.5	2.9
Alnus sinuata	15	.5	5.7
Shepherdia canadensis	10	.4	5.7
Rubus parviflorus	10	.4	5.7
Aster spp.	10	.4	5.7
Antennaria racemosa	10	.4	5.7
Festuca idahoensis	5	.2	2.9
Festuca scabrella	5	.2	2.9
Rosa sp.	5	.2	2.9
Amelanchier alnifolia	5	.2	2.9
Pachistima myrsinites	5	.2	2.9
Total		100.0	

Table 29 Summary of percent cover and percent occurrence of undergrowth species in the Mixed Coniferous Forest Complex of the Temperate Zone (36 plots).

Vegetation	Total Percent Vegetative Cover	Percent Vegetation	Percent Occurrence
Vaccinium scoparium	1150	32.5	94.4
Menziesia ferruginea	605	17.1	38.9
Xerophyllum tenax	585	16.5	83.3
Vaccinium globulare	225	6.4	41.7
Shepherdia canadensis	170	4.8	27.8
Arnica cordifolia	165	4.7	36.1
Trace forbs	165	4.7	63.9
Alnus sinuata	80	2.3	8.3
Juniperus communis	70	2.0	16.7
Spiraea betulifolia	60	1.7	25.0
Aster spp.	60	1.7	19.4
Carex geyeri	40	1.1	11.1
Pachistima myrsinites	30	.8	13.9
Calamagrostis rubescens	25	.7	11.1
Ledum glandulosum	20	.6	5.6
Thalictrum occidentale	20	.6	8.3
Arctostaphylos uva-ursi	10	.3	2.8
Symphoricarpos albus	10	.3	2.8
Salix spp.	10	.3	2.8
Lupinus argenteus	10	.3	5.6
Epilobium angustifolium	10	.3	5.6
Berberis repens	5	.1	2.8
Fragaria virginiana	5	.1	2.8
Senecio triangularis	5	.1	2.8
Antennaria spp.	5	.1	2.8
Total		100.1	

and occurring in 94.4% of the samples (Table 29). *Xerophyllum tenax* and *Vaccinium globulare* were other abundant species.

Accuracy Tests of Computer Maps for the Primary Study Area

Applying the second generation map in the field proved to be an excellent method of judging its accuracy. When enlarged to 3-inches-to-the-mile (1:21120), pixel-sized areas and landform and vegetation groupings could be located on the ground and identified. The small mapping unit of 1.12 acres (.45ha) and the lack of altitudinal zoning precluded direct comparison of the second generation thematic map with the land habitat type map (Fig. 37). However, when the computer classifications for the third generation map were tested against discrete field test sites at prescribed elevations (Hoffer et al. 1975), map accuracy could be numerically expressed and compared. Photographic visualization tests comparing computer classifications with photographs of vegetation groupings and landforms also proved a satisfactory test of mapping accuracy.

Field Test Sites - Scapegoat

The results of the accuracy tests employing 336

field test sites are presented in Table 30. Test sites for vegetation complexes within each of the three climatic zones were altitudinally grouped. Nine of the major complexes were tested (Fig. 15). On an average, the three alpine complexes were accurately identified thematically in 91% of the test samples. Vegetation complexes in the subalpine zone ranged in accuracy from 78% for the Xeric Pinus Albicaulis Forest Complex to 98% for the Mesic Abies Lasiocarpa/Pinus Albicaulis Forest Complex. Overall accuracy for the three subalpine and three temperate zone vegetation complexes was 88% each. The entire Scapegoat area was computer mapped with an accuracy of 89%. This value indicates that 89% of 1546 pixels (28.7% sample) representing the 336 field test sites was classified as correctly representing the ground truth established for each complex.

A total of 175.6 pixels apparently did not represent the established ground truths and were initially considered to be misclassified. Table 31 shows the categories of misclassification for each vegetation complex tested. For example, of the 188.6 pixels representing the 41 test sites in the Alpine Meadow Complex, 9.2 registered as Vegetated Rock and 4.6 as Bare Rock or a 7.3% misclassifi-

Table 30. Accuracy of the Computer Map as Determined from Field Test Sites in the Scapegoat Study Area.

Vegetation Complex Tested	Elevational Separations	Number Test Sites	Number Pixels	Number Accurate	Percent Accurate
Alpine Meadow		41	188	175	93
Vegetated Rock		31	142	130	91
Bare Rock		29	133	117	88
Subtotal Alpine Area	< 7600 feet	101	465	422	91
Xeric Pinus Albicaulis Forest		50	230	179	78
Mesic Abies Lasiocarpa/ Pinus Albicaulis Forest		40	184	179	98
Subalpine Parkland		45	207	184	89
Subtotal Subalpine Area	7000 -7600 feet	135	621	542	88
Xeric Pseudotsuga Menziesii/ Abies Lasiocarpa Forest		30	138	111	80
Mixed Coniferous Temperate Forest		40	184	177	96
Temperate Parkland		30	138	117	85
Subtotal Temperate Area	> 7000 feet	100	460	405	88
Total Study Area	4000 -9200 feet	336	1546	1370	89

Table 31 Misclassification of Pixels in Test Sites of the Scapegoat Study Area.

Vegetation Complex	Misclassified Pixels in Complex Tested					
	Alpine Meadow		Vegetated Rock		Bare Rock	
	Number	Percent	Number	Percent	Number	Percent
Alpine Meadow (41)			4.6	3.2		
Vegetated Rock (31)	9.2	4.9				
Bare Rock (29)	4.6	2.4	8.2	5.8	15.8	13.4
Alpine Zone Misclassified Pixels	13.8	7.3	12.8	9.0	15.8	13.4
	Xeric Pinus Albicaulis Forest		Mesic Abies Lasiocarpa/ Pinus Albicaulis Forest		Subalpine Parkland	
	Number	Percent	Number	Percent	Number	Percent
Xeric Pinus Albicaulis Forest (50)			4.3	2.3	18.1	8.7
Mesic Abies Lasiocarpa/Pinus Albicaulis Forest (40)	32.2	14.0			4.6	2.2
Subalpine Parkland (45)	19.1	8.3				
Subalpine Zone Misclassified Pixels	51.3	22.3	4.3	2.3	22.7	11.0
	Xeric Pseudotsuga Menziesii/Abies Lasiocarpa Forest		Mixed Coniferous Temperate Forest		Temperate Parkland	
	Number	Percent	Number	Percent	Number	Percent
Xeric Pseudotsuga Menziesii/ Abies Lasiocarpa Forest (30)			7.1	3.9	16.1	11.7
Mixed Coniferous Temperate Forest (40)	17.5	12.7			4.3	3.1
Temperate Parkland (30)	9.9	7.2				
Temperate Zone Misclassified Pixels	27.4	19.9	7.1	3.9	20.4	14.8
Misclassified Pixels Study Area	175.6					

( ) Number of test sites per complex.

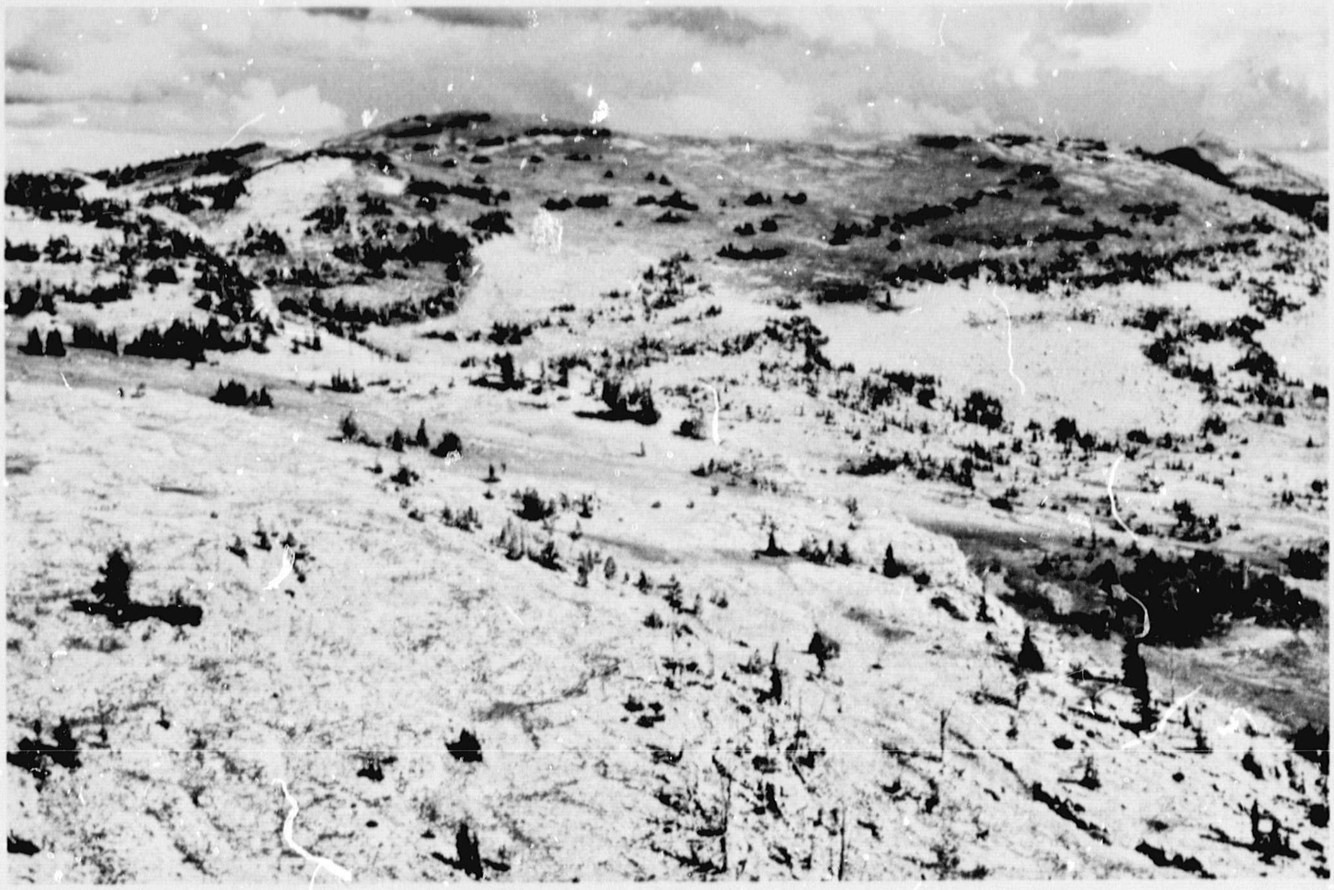
cation. Similarly, 4.6 and 8.2 pixels of the 142.6 tested for the Vegetated Rock Complex registered as Alpine Meadow and Bare Rock, respectively. A higher percentage of pixels were misclassified in the forest and parkland complexes of the sublapine and temperate zones.

I suspected that vegetation gradients within the test sites accounted for a number of misclassified pixels. Accordingly, I re-examined some test sites on the ground and others with the aid of colored aerial photographs using the technique discussed under METHODS. Pixels lying within visible vegetation gradients were termed ecotone inclusions (Figs. 30, 31, and 32). An analysis of these pixels occurring in all complexes showed that 80 of the 176 misclassified pixels were indeed representing vegetation gradients from one complex to another and, as such, were not misclassified. They could be considered correct for more than one theme (Table 32). In comparing accuracy of classification with and without ecotone inclusions, the greatest variation (9.7%) occurred for the Xeric Pinus Albicaulis Forest Complex (gray level values of 16-33 μm in band 7 and 10-16 μm in band 5). This forest complex graded into the open-canopied Subalpine

Fig. 30 Ecotones, gradients between two vegetation complexes, were not readily discernable in the field.

Top: Ecotone gradients between the Alpine Meadow and the Vegetated Rock Complexes.

Bottom: Ecotone mosaic of Xeric Pinus Albicaulis Forest and Subalpine Parkland Complexes.



C-3

Fig. 31 The forested area shown in the photograph was mapped on the ground as Xeric Pinus Albicaulis Forest Complex (habitat type 831).

The computer mapped the area as a mosaic of this forest complex and as Subalpine Parkland Complex. Because of the great variation in canopy density, the computer was more discriminating than the ground mappers. Designation of ecotone pixels, within ground test sites, was necessary to refine the accuracy tests.

Fig. 32 Mosaic of light-canopied Xeric Pinus Albicaulis Forest Complex and dense-canopied Mesic Abies Lasiocarpa/Pinus Albicaulis Forest Complex. The accuracy of the computer in discriminating between degrees of canopy coverage (gray level values) was greater than the ability of field personnel to lay out homogenous test sites for the two vegetation complexes where they intergraded. This introduced a negative bias into the accuracy tests. Test sites for the forest area shown in the photograph were initially identified on the ground as representing the Xeric Pinus Albicaulis Forest Complex. The computer classified the forested area as a mosaic of both forest complexes. Designation of ecotonal pixels within the test sites, removed the bias in the accuracy tests (see text).

Table 32 Comparison of Accuracy of the Computer Map as Determined from Field Test Sites With and Without Ecotonal Inclusions in the Scapegoat Study Area.

Vegetation Complex Tested	Grey Level		Without Ecotone Inclusions		With Ecotone Inclusions		
	Band 7	Band 5	Number Test Sites	Percent Accuracy	Ecotone Pixels Included	Percent Accuracy	Percent Accuracy Change
Alpine Meadow	16-35	17-30	41	92.7	4.6	95.1	2.4
Vegetated Rock	16-24	31-65	31	91.0	4.3	94.0	3.0
Bare Rock	25-41	31-127	29	88.2	4.6	91.6	3.4
Subtotal Alpine Zone			101	90.9	13.5	93.8	2.9
Xeric Pinus Albicaulis Forest	16-33	10-16	50	77.7	22.4	87.4	9.7
Mesic Abies Lasiocarpa/Pinus Albicaulis Forest	5-15	6-18	40	97.7	2.0	98.8	1.1
Subalpine Parkland	16-35	17-30	45	89.0	10.2	94.0	5.0
Subtotal Subalpine Zone			135	87.4	34.6	93.0	5.6
Xeric Temperate Forest (Abies, Pseudotsuga)	16-33	10-16	30	80.1	12.6	89.3	9.2
Mixed Coniferous Temperate Forest	5-15	6-18	40	96.1	2.3	97.4	1.3
Temperate Parkland	16-35	17-30	30	85.2	7.9	90.9	5.7
Subtotal Temperate Zone			100	88.1	22.8	93.0	4.9
Total All Zones			336	88.6	70.9	93.2	4.6

Parkland Complex (gray level values of 16-35 μm in band 7 and 17-30 μm in band 5) and into the heavily canopied Mesic Abies Lasiocarpa-Pinus Albicaulis Forest Complex (gray level values of 5-15 μm in band 7 and 6-18 μm in band 5). Similarly, the xeric temperate forest complex of *Abies* and *Pseudotsuga* showed a 9.2% change for the same reasons stated above when ecotone pixels were included. When I considered ecotone pixels within test sites correctly classified if they met canopy coverage and botanical criteria of the theme tested rather than spectral values of an intergrading theme, the total pixels recorded as correctly classified, increased. Using this procedure, I obtained an overall accuracy value of 93.2%; a 4.6% increase in my evaluation of mapping accuracy.

Stated another way, in 336 test sites representing 1546 pixels, 71 or 4.6% were ecotonal and could be considered correctly classified ecologically in two or more themes. When I assigned these to the theme being tested, the numerical expression of accuracy increased. Minor differences in ground cover, canopy density, or a combination of both were the variables determining the gray levels that assigned these pixels to one theme or another. Species composition was not a determining factor.

Accuracy of Extrapolation to Secondary Study Areas

Using the second generation signatures derived for

the primary study area, I constructed computer thematic maps for the Slategoat and Danaher as described under METHODS. The first computer maps of the secondary areas were termed second generation maps. These are shown in Figs. 33 and 34. The vegetation of neither secondary area was ground-mapped prior to computer mapping, but I theorized that the primary area signatures, with computer assistance, should accurately map the secondary areas. The results could be tested in the field and laboratory. If the vegetation complexes, mapped in this way, proved ecologically similar to their color encoded counterparts in the primary area (Fig. 15), then I would have demonstrated computer mapping by extrapolation to be accurate.

To test the theory the secondary areas were type-mapped, then test sites were established in the field. These were located on orthophoto maps and checked against the computer extrapolated thematic maps (see METHODS). These accuracy tests were conducted within the alpine and subalpine zones of Slategoat and the temperate zone of Danaher. I recognized the desirability of standardizing the size of the field test sites, but had no data on optimum size to guide me. Accordingly, I experimented with 5.1 acre (2.1ha) sites for the primary area and 2.7 (1.1ha)

and 6.7 (2.7ha) acre sites for the secondary Slategoat and Danaher areas, respectively.

Field Test Sites - Slategoat

Results of accuracy tests from 456 field test sites in the Slategoat area are presented in Table 33. Accuracy for the three alpine complexes combined was 79%, a 12% reduction in accuracy when compared with the values for the same complexes in the primary study area (Table 30). Accuracy for the subalpine zone complexes was 70%, an 18% reduction in accuracy. The misclassified pixels are listed by complex in Table 34. Many "misclassified" pixels represented ecotonal situations. For example, of 34.75 pixels considered misclassified in the Alpine Meadow Complex, 19.75 were ecotonal and, therefore, correct for the theme tested (Table 35). The Xeric Pinus Albicaulis Forest Complex registered an accuracy of only 58%, as compared to 78% for its counterpart in the primary area. In both study areas, this forest complex exhibited low accuracy values because of vegetation gradients (ecotones) between the complexes tested.

Overall accuracy for the Slategoat extrapolated map was 75%, an apparent 14% loss through extrapolation. To determine whether this was a valid difference due to the

Fig. 33 Slategoat second generation map.

The map was constructed by extrapolating six signatures from the primary Scapegoat Study Area to a secondary area using the G.E. Image 100 Computer. The area of 134.7 square miles ($348.9 km^2$) embraces three climatic zones. The distribution of the color encoded themes shown here, when compared with those for the third generation map (Fig. 42), shows the progress made in the mapping technique.

Key to Color Encoded Themes

	Vegetation Complex	Percent Area
Blue	= Alpine Meadow and Subalpine and Temperate Parklands	23.33
Gold	= Vegetated Rock	6.44
Pink	= Rock I (Limestone)	5.50
Red	= Rock II (Shaded talus slopes and Argillite)	4.11
Green	= Subalpine Fir/Whitebark Pine Forest and Temperate Subalpine Fir/Douglas Fir Forests	17.16
Violet	= Subalpine and Temperate Mixed Coniferous Forests	43.49
TOTAL		100.03

Note: To compare with the second and third generation maps of Scapegoat, see Figs. 11, 28, and 29, respectively.

Table 33 Accuracy of the Computer-Extrapolated Map as Determined from Field Test Sites for the Secondary (Slategoat) Study Area.

Vegetation Complex	Test Sites	Number		Percent Accuracy
		Pixels	Accurate	
Alpine Meadow	81	202.50	167.75	82
Vegetated Rock	53	132.50	95.00	72
Bare Rock	100	250.00	201.75	81
Subtotal Alpine Zone	234	585.00	464.50	79
Xeric Pinus Albicaulis Forest	49	122.50	71.25	58
Mesic Abies Lasiocarpa/Pinus Albicaulis Forest	70	175.00	149.00	85
Subalpine Parkland	103	257.50	165.75	64
Subtotal Subalpine Zone	222	555.00	386.00	70
Total Alpine and Subalpine Zones	456	1140.00	850.50	75

Table 34 Misclassified Pixels in Test Sites of the Secondary (Slategoat) Study Area.

Vegetation Complex	Misclassified Pixels in Complex Tested					
	Alpine Meadow (202.5)*		Vegetated Rock (132.5)*		Bare Rock (250)*	
	Number	Percent	Number	Percent	Number	Percent
Alpine Meadow	0	0	12.75	9.6	.50	0.2
Bare Rock	11.25	5.6	19.50	14.7	0	0
Vegetated Rock	11.00	5.4	0	0	46.00	18.4
Xeric Pinus Albicaulis Forest	8.75	4.3	0	0	0	0
Mesic Abies Lasiocarpa/Pinus Albicaulis Forest	2.50	1.2	.50	.4	0	0
Subalpine Parkland	0	0	4.75	3.6	1.25	0.5
Unclassified	1.25	0.6	0	0	.50	0.2
Alpine Zone Misclassified Pixels	34.75	17.2	37.50	28.3	48.25	19.3
	Xeric Pinis Albicaulis Forest (122.5)*		Mesic Abies Lasiocarpa/ Pinus Albicaulis Forest (175.0)*		Subalpine Parkland Complex (165.75)*	
	Number	Percent	Number	Percent	Number	Percent
Xeric Pinus Albicaulis	0	0	24.25	13.9	54.25	32.7
Mesic Abies Lasiocarpa/Pinus Albicaulis Forest	40.50	33.1	0	0	9.00	5.4
Subalpine Parkland	8.75	7.1	0	0	0	0
Bare Rock	1.00	.8	0	0	11.00	6.6
Vegetated Rock	0	0	0	0	6.25	3.8
Unclassified	1.00	.8	1.75	1.0	11.25	6.8
Subalpine Zone Misclassified Pixels	51.25	41.8	26.0	14.9	91.75	55.4
Misclassified Pixels Study Area	289.50					

* ( ) Total pixels in the complex.

Table 35 Accuracy of the Computer-Extrapolated Maps as Determined from Field Test Sites With and Without Ecotonal Inclusions for the Secondary (Slategoat) Study Area.

Vegetation Complex Tested	Without Ecotone Inclusions: Number Test Sites	Without Ecotone Inclusions: Percent Accuracy	With Ecotone Inclusions: Ecotone Pixels Included	With Ecotone Inclusions: Percent Accuracy	With Ecotone Inclusions: Percent Accuracy Change
Alpine Meadow	81	82.8	19.75	92.6	9.8
Vegetated Rock	53	71.7	17.50	84.9	13.2
Bare Rock	100	80.7	45.50	98.9	18.2
Subtotal Alpine Zone	234	79.4	82.75	93.5	14.1
Xeric Pinus Albicaulis Forest	49	58.2	29.00	81.8	23.6
Mesic Abies Lasiocarpa/ Pinus Albicaulis Forest	70	85.1	13.00	92.6	7.5
Subalpine Parkland	103	64.4	57.00	86.5	22.1
Subtotal Subalpine Zone	222	69.5	99.00	87.2	17.7
Total Alpine and Subalpine Zones	456	74.6	181.75	90.5	15.9

extrapolation process rather than imprecise methodology for testing, I made corrections that would accomodate the "ecotone" pixels (Table 35). The greatest accuracy changes occurred in the Bare Rock, Xeric Pinus Albicaulis Forest, and Subalpine Parkland Complexes. The inclusion of 181.75 ecotonal pixels raised the overall extrapolation accuracy rating to 91%, a value comparable to the 93% accuracy for the primary study area. These values indicate that the initial testing method required refinement. I concluded that extrapolation was extremely accurate. Use of the maps in the field further verified this conclusion. The differences in gray level values between themes, represented subtle differences in canopy and ground cover density that were not recognized as significant criteria when the field test sites were established.

Field Test Sites - Danaher

Accuracy tests for the temperate zone - Danaher area (Fig. 34) showed an overall initial accuracy of 75% (Table 36). Once again the xeric forest and parkland themes exhibited the highest percentage of misclassified pixels (Table 37). They also exhibited a higher percentage of ecotonal pixels, which is consistent with results for both the Scapegoat and Slategoat areas. The determination that

Fig. 34 Danaher second generation thematic map.

The map was constructed by extrapolating signatures from the Scapegoat primary study area to the Danaher. Over 93% of the 41.7 square miles ($108km^2$) Danaher study area lies within the temperate climatic zone.

Key to Color-Encoded Themes

	Vegetation Complex	Percent Area
Blue =	Alpine Meadow and Subalpine and Temperate Parkland	9.29
Gold =	Vegetated Rock	.90
Pink =	Rock I (Limestone)	.64
Red =	Rock II (Shaded talus slopes and Argillite)	1.39
Green =	Subalpine Fir/Whitebark Pine Forests and Temperate Subalpine Fir/Douglas Fir Forests	18.39
Violet =	Subalpine and Temperate Mixed Coniferous Forests	69.42
TOTAL		100.03

Note: To compare with the third generation map of Danaher see Fig. 43. Note especially the Carex-Salix Marsh Complex color-encoded gold-brown. This complex was differentiated from the surrounding Temperate Parkland Complex (gray-blue) and the Mixed Coniferous Forest Complex (violet) by employing a signature polygon.

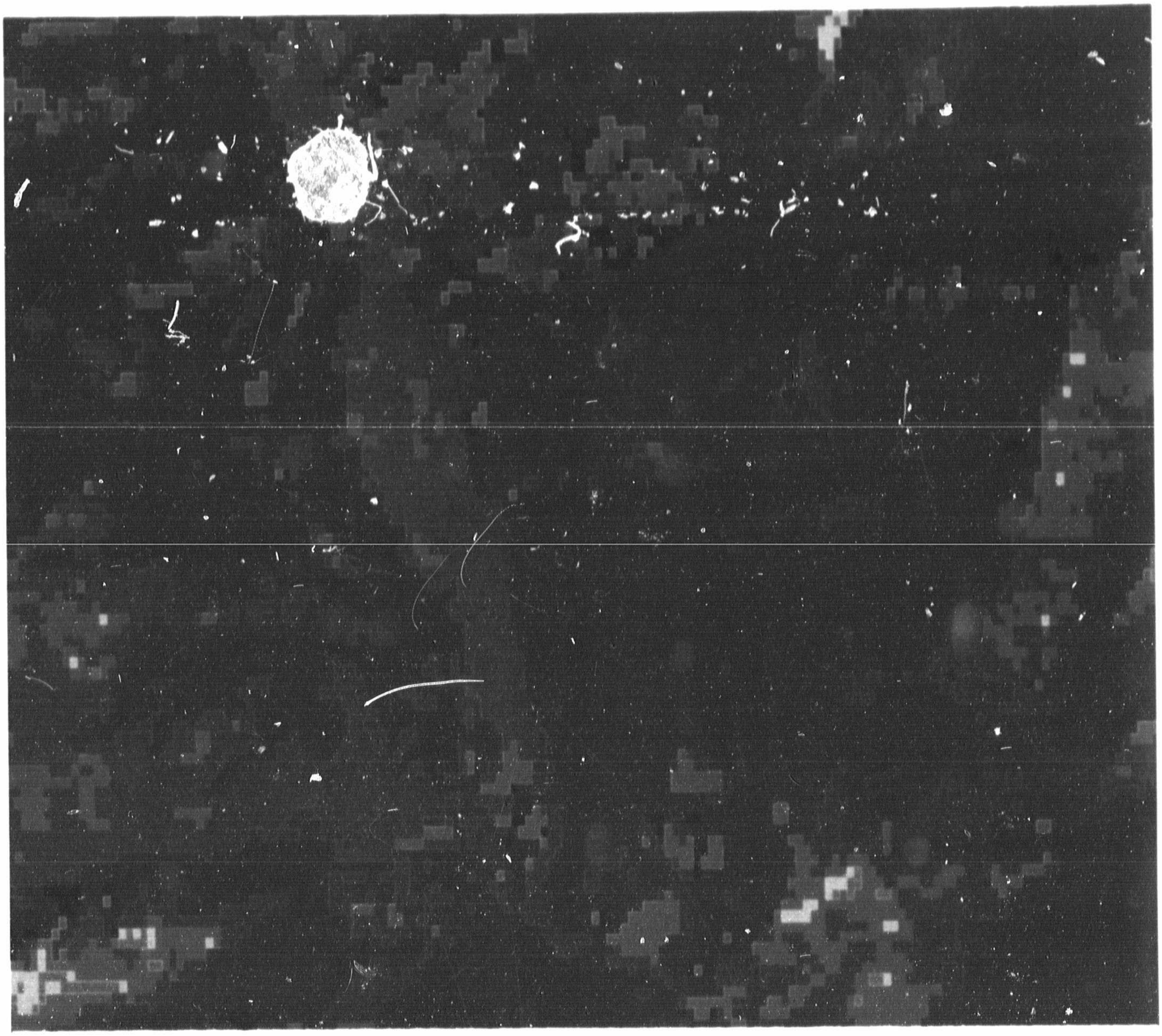


Table 36 Accuracy of the Computer-Extrapolated Map as Determined from Field Test Sites for the Secondary (Danaher) Study Area.

Vegetation Complex Tested	Test Sites	Number		Percent Accuracy
		Pixels	Accurate	
Xeric Abies Lasiocarpa/Pseudotsuga Menziesii Forest	60	360	202	56
Mixed Coniferous Temperate Forest	50	300	299	100
Temperate Parkland	30	180	131	73
Total Temperate Zone	140	840	632	75

Table 37 Misclassified Pixels in Test Sites for the Secondary (Danaher) Study Area.

Vegetation Complex	Misclassified Pixels in Complex Tested: Xeric Abies Lasiocarpa/ Pseudotsuga Menziesii Forest (360)*		Mixed Coniferous Temperate Forest (300)*		Temperate Parkland (180)*	
	Number	Percent	Number	Percent	Number	Percent
Xeric Abies Lasiocarpa/ Pseudotsuga Menziesii Forest	0	0	1	.3	6	3.3
Mixed Coniferous Forest	120	33.3	0	0	5	2.8
Temperate Parkland	38	10.6	0	0	0	0
Bare Rock	0	0	0	0	38	21.1
Misclassified Pixels Study Area	158	43.9	0	0	49	27.2

* ( ) Total pixels in the complex.

Table 38 Accuracy of the Computer-Extrapolated Map as Determined from Field Test Sites With and Without Ecotonal Inclusions for the Danaher Study Area.

Vegetation Complex Tested	Without Ecotone Inclusions: Number Test Sites	Without Ecotone Inclusions: Percent Accuracy	With Ecotone Inclusions: Ecotone Pixels Included	With Ecotone Inclusions: Percent Accuracy	With Ecotone Inclusions: Percent Accuracy Change
Xeric Temperate Forest	60	56.1	38	66.7	10.6
Mixed Coniferous Temperate Forest	50	99.7	0	99.7	0
Temperate Parkland	30	72.8	44	97.2	24.4
Total Temperate Zone	140	75.2	82	85.0	9.8

ecotonal pixels were correctly classified for the theme tested, increased the percent accuracy to 85% (Table 38). Accuracy tests for all three areas are summarized in Table 39.

The use of the test site technique yielded an initial low accuracy value. This occurred because the computer reading of gray level values in 1.12 acre (.45ha) units (pixels) was more precise than my ability to delineate larger homogeneous test sites on the ground. Accuracy tests improved with the recognition of ecotonal pixels.

The test results from all three study areas showed a high and consistent correlation between spectral classes and the ground truth data they represented.

Comparison of Area Statistics for Conventional Ground Type Map Versus Computer-Modeled Map

As another test of accuracy I compared the ground truth map of Scapegoat (Fig. 37) with the third generation computer map of the same area (Fig. 15). The close agreement in vegetation distribution patterns, for the two maps, in itself is visual evidence of accuracy. Difficulty was encountered comparing area statistics because of differences in mapping technology. By consolidating the

Table 39. Summarized comparison of accuracy tests.

Study Areas	Mapping Procedure	Number of Test Sites	Number of Zones	Size of Test Sites (Pixels)	Percent Accuracy: Field Test Sites	Percent Accuracy: Apparent Loss to Extrapolation	Percent Accuracy: With Ecotonal Inclusions	Percent Accuracy: Change
Primary Scapegoat	Orig. Signatures	336	3	4.6	88.6		93.2	4.6
Secondary Slategoat	Extrapolation	456	2	2.4	74.6	14.0	90.5	15.9
Secondary Danaher	Extrapolation	140	1	6.0	75.2	13.4	85.0	9.8

vegetation units of both maps into ecologically similar groupings (Table 40 and Fig. 38) a comparison of area statistics was possible. The results (with certain explainable exceptions) support the previous accuracy determinations.

The Alpine Meadow Complex with an area value of 7.88% versus 4.97% for the ground map would appear to be inaccurate; however, the lack of close agreement is primarily due to more precise altitude zoning by the computer than was possible on the ground. Group IV, the *Abies lasiocarpa*/*Pinus albicaulis* forests of the ground map show rather close agreement with ecologically comparable values for the computer map: the comparative values being 36.39 and 32.84%, respectively. The difference of 3.55% is explainable. Very open *Pinus albicaulis* forests (canopy cover 15% and less) were classified as subalpine parkland rather than forest types, by the computer using spectral values. This reduced the total acreage computer-assigned as *P. albicaulis* forest but increased the computer-assigned parkland acreage (Fig. 29). This is not an error in computer mapping but rather a change in area statistics that accompanied the change in the classification method. Similarly explainable is the 11% discrep-

Table 40 Comparison of area statistics of ground map versus computer map as a test of accuracy, Scapegoat Study Area.

Category	Area Acres Ground Map	Area Acres Computer Map	Percent Acres Ground Map	Percent Acres Computer Map
I Alpine Meadow Landtype	2014		3.99	
Forest Intrusion	490		.99	
Subtotal	2504		4.97	
I Alpine Meadow Complex		3905		7.88
II Vegetated Rock Landtype	2764		5.49	
II Vegetated Rock Complex		2875		5.80
III Bare Rock Landtypes	2478		4.92	
Rock and Talus	1268		2.51	
Subtotal	3746		7.43	
III Bare Rock Complex I and II		4036		8.14
IV Abies Lasiocarpa Forest with Pinus Albicaulis	18330		36.39	
IV Xeric Pinus Albicaulis Forest Complex		3966		9.30
Mesic Abies Lasiocarpa/Pinus Albicaulis Forest Complex		10034		23.54
Subtotal		14000		32.84
V Abies Lasiocarpa Forest Without Pinus Albicaulis-Vaccinium spp. common	18685		37.10	
Wet Forest Vaccinium spp. variable	442		.90	
Subtotal	19127		38.00	

Table 40 Continued

Category	Area Acres Ground Map	Area Acres Computer Map	Percent Acres Ground Map	Percent Acres Computer Map
V Mixed Coniferous Forest Complex		13385		27.01
VI Dry Forest with Vaccinium spp. absent	2059		4.09	
VI Xeric Abies Lasiocarpa Pseudotsuga Menziesii Forest Complex		3233		6.53
VII Meadow, Glades, Snowslides and SCREE	1839		3.65	
VII Subalpine Parkland Complex		4136		
Temperate Parkland Complex		2983		
Carex-Salix Marsh		15		
Equisetum Seepage		120		
SCREE (Trees)		760		
Subtotal		8014		16.17
Unclassified		102		.23
Grand Total				
Landtypes	50365		100.01	
Complexes		49563		100.07

ancy between area statistics of 38% for the <u>Abies lasiocarpa</u> forests without <u>Pinus albicaulis</u> (ground map) and the 27% for the Mixed Coniferous Forest Complex of the computer map.

The Seral Forest Stages (Burns) of the ground map were classified as forest habitat types whereas the computer classified these as subalpine and temperate parkland (Figs. 35 and 36) (see also Fig. 28, second generation map). Again, this represents a deliberate change in classification, and is not a mapping error. For computer modeling, I considered the Seral Forest Stages (Fig. 35) as grass-shrub landtypes rather than seral forest habitat types. This placed it within the parkland complexes ecologically and spectrally. Because of this decision, computer modeling reduced the acreage assigned to forest groups IV and V and computed a comparable acreage increase in Group VII, the grass-shrubland landtypes. A change in the latter category from 3.65% for the ground map to 16.17% for the computer map (more than a four-fold area increase) is again the result of a deliberate change in classification introduced into the computer model. An approximation of the classification changes resulting from the computer modeling are shown in Fig. 38. The

Fig. 35 The extensive burn in foreground was type-mapped as forest habitat types of the *Abies lasiocarpa* series (Fig. 37). The computer classified the same area as Subalpine Parkland (Fig. 29). This was a deliberate change from a purely ecological classification to an eco-spectral one. The resulting difference in area percentages is shown in Fig. 38.

Fig. 36 The eco-spectral classification registered the foreground in upper photograph as Subalpine Parkland Complex phasing into Temperate Parkland Complex below 7000 feet (2134m). The ground map classified the area as forest habitat types of the respective climatic zones.

Lower photograph illustrates ecotone areas intergrading from Subalpine Parkland Complex to Xeric Pinus Albicaulis Forest Complex. Such ecotonal areas complicated interpretation of accuracy tests.

Fig. 37 Vegetation type map of the Scapegoat area. This map, based on intensive sampling, shows the ecological land units, landtypes, and forest habitat types as they occurred in the field. This "ground truth" was used to check the accuracy of the computer map.

Color groupings of the various landtypes are similar to the color codes of the third generation computer map (Fig. 29). For example, violet shades are generally equivalent to the Mixed Coniferous Forest Complex, light and dark green to the Xeric Pinus Albicaulis and Mesic Abies Lasiocarpa/Pinus Albicaulis Forest Complexes and yellow and blue hues to the Vegetated Rock and Alpine Meadow Complexes, respectively.

Note: This vegetation type map was presented in Section I but is reproduced here in Section III to facilitate comparison of Fig. 37 with Fig. 29.

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Vegetation Type Map
GRIZZLY BEAR HABITAT
Lincoln-Scapegoat Wilderness

ALPINE ECOLOGICAL LAND UNITS AND LANDTYPES*

SUBALPINE AND TEMPERATE FOREST HABITAT TYPES**

SUBALPINE AND TEMPERATE GRASS-SHRUBLAND LANDTYPES***

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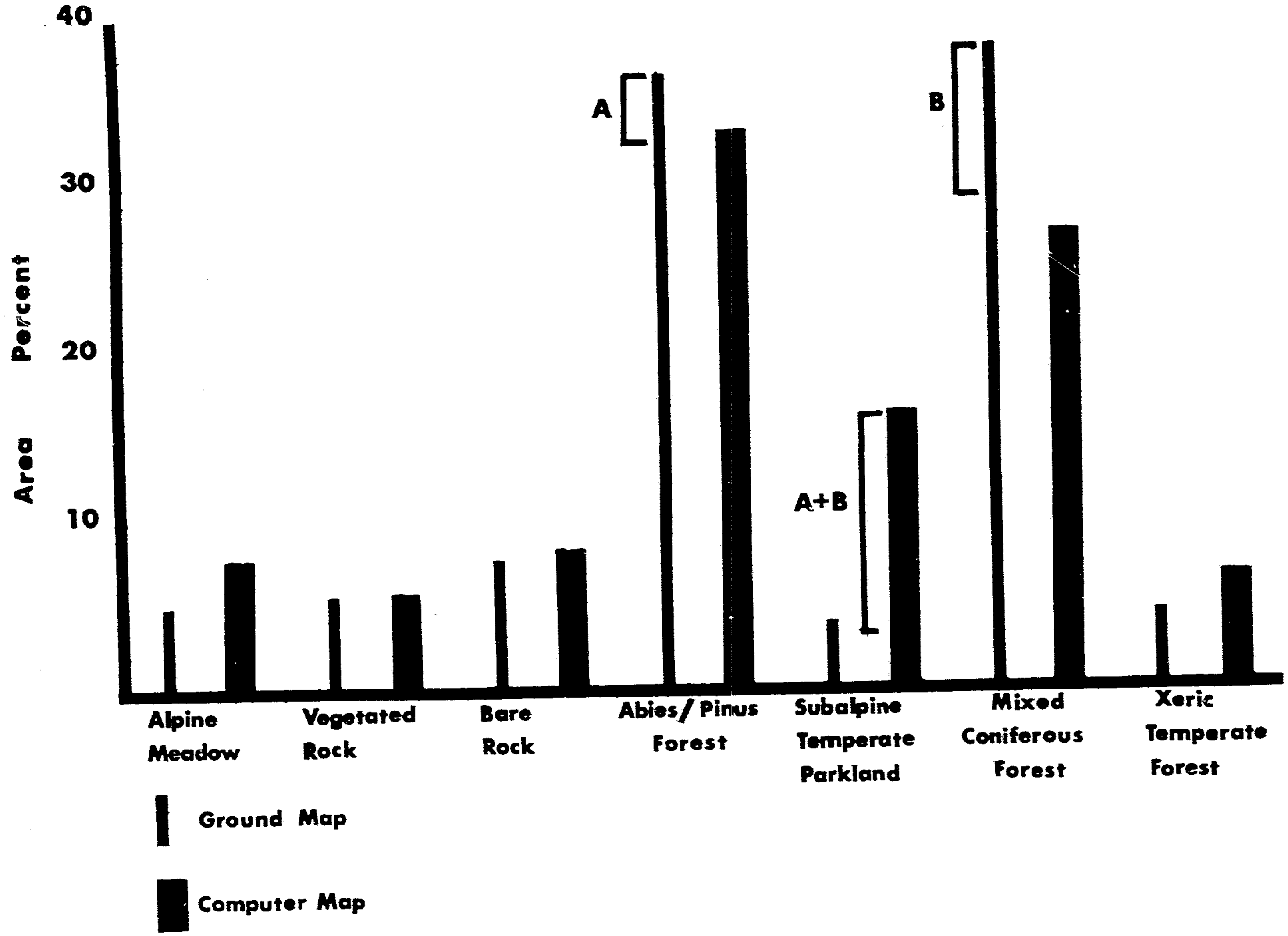
Fig. 38 Comparison of area statistics for the ground vegetation type map (Fig. 37) and the third generation computer map (Fig. 29). The wide line represents the computer map; the narrow line the ground type map. The portion of the graph lettered A and B shows where the greatest change in classification occurred.



40
30
20
10
Area Percent
A
B
A+B
Alpine Meadow
Vegetated Rock
Bare Rock
Abies/Pinus Forest
Subalpine Temperate Parkland
Mixed Coniferous Forest
Xeric Temperate Forest
Ground Map
Computer Map

computer classified forests with canopy coverage of less than 15% and the seral forests (burns) as subalpine and temperate parkland. These were classified on the ground map (ground truth) as forest types. The spectral signature values dictated the computer designation. This again made direct comparison difficult. However, I desired to computer-map, as a single theme, the open grasslands and early seral stages resulting from burns. When the inherent differences in the two classification systems were considered, I concluded that area statistics showed close agreement between the ground and the computer-modeled map in all categories.

Land-Habitat Type Visualization

I checked the second and third generation maps in the field to determine if large units of the landscape were consistently and correctly mapped (Fig. 39). I perceived that alpine meadow was computer-mapped as alpine meadow and accurately separated from the sparsely vegetated rock and this, in turn, from the bare rock peaks and ridges. Figure 40 exemplifies the appearance of vegetation/rock classes on the ground and their representation by the spectral themes. A careful scrutiny of

Fig. 39 Field checking the third generation computer map of Scapegoat. Vegetation complexes delineated by signature polygons were checked for elevational accuracy and for vegetation composition.

Fig. 40 Seven spectral themes are displayed on the computer map (center photograph). Visual representations of these rock-vegetation themes, as they appeared on the ground, are shown in the eight peripheral photographs. To check theme color on the computer map with the rock or vegetation class each represents, follow the yellow guide lines.

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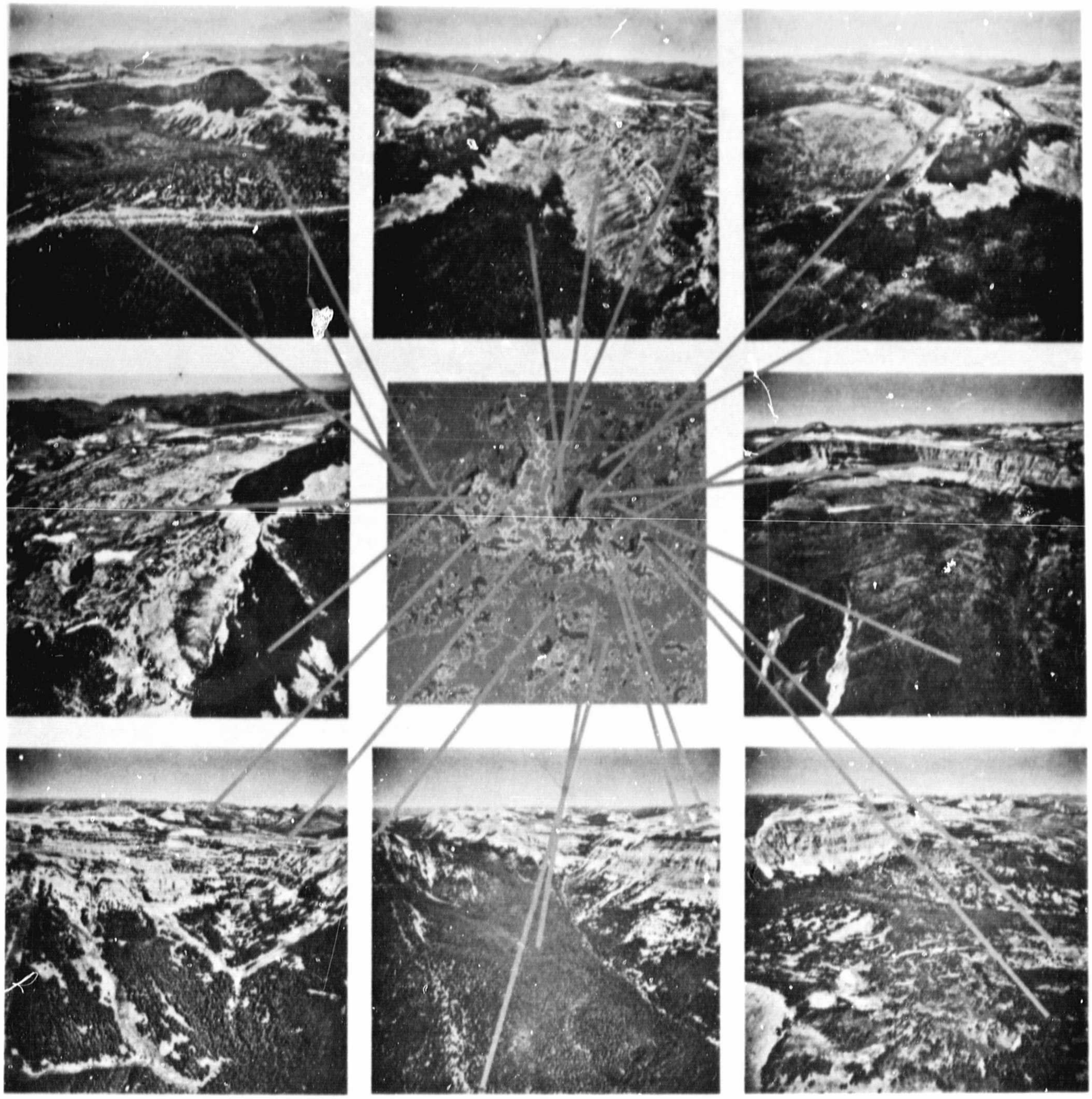


Vegetation/Rock Classes (Spectral Themes)

- Alpine Meadow
- Bare Talus Slopes and Argillite Rock
- Parent Rock (Largely Limestone)
- Subalpine Fir - Whitebark Pine Forest
- Vegetated Rock
- Subalpine and Temperate Parkland
- Subalpine and Temperate Mixed Coniferous Forests
- Temperate Subalpine Fir - Douglas Fir Forest

Fig. 40 will show that the light and the heavy canopied forests were consistently represented by the green and violet colored-codes, respectively. Similarly, the open grass-shrub ridges, wet and dry meadows, SCREE, and early seral stage burns were consistently represented by the dark blue color code corresponding to the subalpine and temperate parklands. I gained confidence in the accuracy of the computer maps by using them with 3-inches-to-the-mile (1:21120) contour overlays to locate specific landforms and vegetation features in the field. With practice it was possible to use the computer maps as effectively as the contoured orthophotos enlarged to the same scale.

Problem Areas

Severe, recent burning of coniferous forests on shallow argillite soil presented a spectral problem for the computer modeling. In these areas of the sublapine zone, vegetation in early grass-shrubland successional stages eventually evolve to climax *Abies lasiocarpa* forests; or in the temperate zone to *Pseudotsuga menziesii* forests. Computer modeling misclassified some of these sites as the Mixed Coniferous Forest Complex. I believe the misclassification occurred because exposed dark red

soil of argillite origin with sparse vegetation produced a spectral reflectance that closely matched the spectral values of the dense canopied Mixed Coniferous Forest Complex (Fig. 41).

Another misclassification occurred on the northeast aspects of the 1000 foot (305m) vertical "Chinese Wall" in the Slategoat area. The east-facing limestone walls registered as bare limestone rock (gray level values of 31 to 127 μm in band 5 and 16 to 50 μm in band 7 (Fig. 20). The northeast exposures, of identical limestone strata, registered as vegetated rock or as SCREE with gray level values of 31 to 65 μm in band 5 and 16 to 24 μm in band 7. This descrepancy was attributed to shadow effect from the low sun angle (Fig. 41).

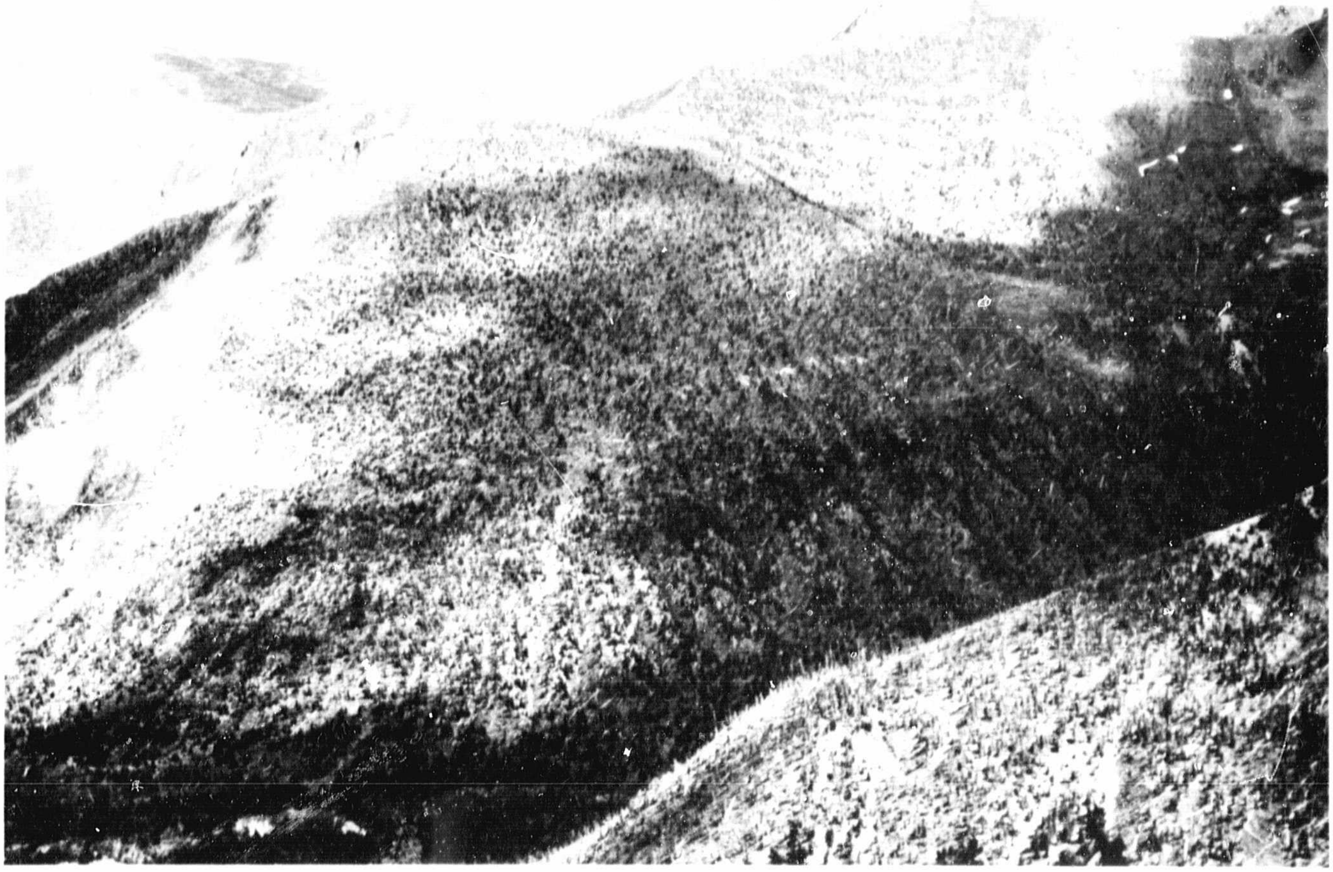
The problem areas I have identified and discussed comprise less than 1% of the total land area mapped. They contributed to the misclassifications recorded in my accuracy tests. I considered them relatively insignificant.

Scene Illumination Effects

The sun angle above the horizon for 28 Augsut 1972 imagery was 46.0° elevation, 143.0° azimuth. North-northwest facing slopes (NE, N, NW, and W) received less light than south and east facing ones (E, SE, S, and SW).

Fig. 41 The northeast projections of the limestone escarpment shown in upper photograph were problem areas for computer mapping because of the shadow effect due to low sun angle.

Severe, recent burns shown in lower photograph exposed dark red argillite soil that presented a spectral problem.



This resulted in tonal variations due to shadowing. Intensive ground surveys showed that the exposures receiving less illumination supported heavy-canopied vegetation characteristic of mesic sites. My data indicated the "shadow effect" intensified the spectral differences that occurred between the two aspect oriented vegetation groupings. The basic vegetation ecology (mesic and xeric type vegetation represented by heavy versus light canopy) was, to a large extent, governed by annual light intensity. I concluded that the "shadow effect" was simply reinforced by the mountainous topography where I was working. Had all exposures received the same illumination in the frame of 28 August, I still would have obtained two unique signatures; one distinguishing mesic vegetation themes on NE, N, NW, and W aspects and another characterizing xeric vegetation on E, SE, S, and SW aspects.

Where the topography was extremely precipitous, very dark shadows occurred. Vegetation types occurring in these poorly illuminated sites (usually associated with extremely heavy snow packs and short growing seasons) were consistently characteristic of such sites (Fig. 23). Though the imagery revealed no details in the deep shadows, the vegetational homogeneity was evident from on-site sampling.

Quantitative Descriptions of Vegetation Complexes Third Generation Maps

Vegetation descriptions of the complexes comprising the third generation maps for all three study areas are shown in Tables 14, 41, and 42. Percent area for each of the 13 complexes and the percent vegetation composition of each ELU, ELT, or HT (habitat type) can be readily interpreted by referencing the Scapegoat map, Fig. 29 with Table 14. For example, the Alpine Meadow Complex depicted in light blue on the Scapegoat map represents 7.88% of the total map area and consists of 32, 25, 23, 17, and 3% Alpine Meadow Krummholz, Alpine Meadow, Slab Rock Krummholz, Slab Rock Steps, and Vegetated Talus, respec-pectively. Greater botanical detail can be obtained from Tables 18 and 19 which show the percent vegetation and percent occurrence by species of plants composing the Alpine Meadow Complex. *Carex* species, *Festuca idahoensis*, and *Dryas octopetala* are the most abundant with percents of 21, 16, and 6.6, respectively. For still greater detail, a species breakdown by ELUs is presented in Section I Appendix, Tables 1-5.

Complex V, the Xeric Pinus Albicaulis Forest (shown in green), represents 8.01% of the total land area and is composed of seven habitat types and phases and SCREE, with percent compositions as shown in Table 14. Among the habitat types Abies lasiocarpa/Luzula hitchcockii, Vaccinium scoparium phase (831) predominated, representing 42% of the complex. Habitat types 820 and 850 rate second and third, respectively, in percent occurrence or composition within the complex. More detailed botanical descriptions can be obtained by reference to Table 24 or to Pfister et al. (1977).

The other eleven complexes described in Table 14 can be similarly referenced to the map (Fig. 29) and interpreted in terms of their botanical compositions. Quantitative description for Complexes XIII, VIII, and XII are not presented in Table 14 because of the small areas involved; however, a qualitative description is available from descriptive matter in the text.

Slategoat

The vegetation complexes occurring in the Slategoat area are quantified in Table 41 and can be used to interpret the map of the area shown in Fig. 42.

Table 41 Description of vegetation complexes representing a spectral classification for the third generation computer map of the Slategoat Study Area.

ALPINE CLIMATIC ZONE (>7600')

Vegetation Complex (Class)	Percent Area	Description and Composition by Ecological Land Units	Occurrence	Percent Occurrence (Composition)*
Complex I: ALPINE MEADOW	5.26	Climax Vegetation: Carex spp.		
		Alpine Meadow Krummholz	167	83
		Alpine Meadow	29	15
		Vegetated Talus	4	2
		Total	200	100
Complex II: VEGETATED ROCK	3.03	Climax Vegetation: Dryas octopetala		
		Mountain Massif	96	58
		Semi-vegetated Talus	35	12
		Fellfield	21	21
		Veg. Rock and Krummholz	9	5
		Bare Talus	6	4
		Total	167	100
Complex III: BARE ROCK I	5.49	Climax Vegetation: Lichens		
		Parent Rock-Limestone	64	53
		Bare Talus	52	43
		Semivegetated Talus	5	4
		Total	121	100
Complex IV: BARE ROCK II	4.44	Climax Vegetation: Lichens		
		Parent Rock-Argillite	28	60
		Bare Talus in shadow	19	40
		Total	47	100

*Percent composition of vegetation complexes was calculated employing the grid overlay with the third generation computer map (See METHODS).

Table 41 Continued.

SUBALPINE CLIMATIC ZONE (7600'-7000')

Vegetation Complex (Class)	Percent Area	Description and Composition by Forest Habitat Types or by Ecological Landtypes	Occurrence	Percent Occurrence (Composition)*
Complex V: XERIC PINUS ALBICAULIS FOREST; predom. E, SE, S, SW exposures; light canopy (15-35%).	4.14	Climax Vegetation: Abies lasiocarpa		
		831 Abies lasiocarpa/Luzula hitchcockii-Vaccinium scoparium	120	68
		820 Abies lasiocarpa(Pinus albicaulis)/Vaccinium scoparium	40	23
		850 Pinus albicaulis-Abies lasiocarpa	12	7
		010 SCREE	4	2
		Total	176	100
Complex VI: MESIC ABIES LASIOCARPA/PINUS ALBICAULIS FOREST; predom. NE, N, NW, W exposures; moderate to heavy canopy cover (35%).	9.32	Climax Vegetation: Abies lasiocarpa		
		831 Abies lasiocarpa/Luzula hitchcockii-Vaccinium scoparium	64	44
		820 Abies lasiocarpa(Pinus albicaulis)/Vaccinium scoparium	52	36
		850 Pinus albicaulis-Abies lasiocarpa	12	8
		832 Abies lasiocarpa/Luzula hitchcockii-Menziesia ferruginea	8	6
		860 Larix lyallii-Abies lasiocarpa	8	6
		Total	144	100
Complex XIII: SCREE (grass-forb)	3.39	Festuca idahoensis, Carex spp.	-	-
Complex VII: SUBALPINE PARKLAND	8.80	Climax Vegetation: Festuca spp., Abies lasiocarpa		
		Xeric-mesic seral forest stages (burns)	116	61
		Xeric subalpine grass-shrublands	60	31
		SCREE	16	8
		Total	192	100
Complex VIII EQUISETUM SEEPAGE	.35	Equisetum arvense, Pedicularis groenlandica	2	100

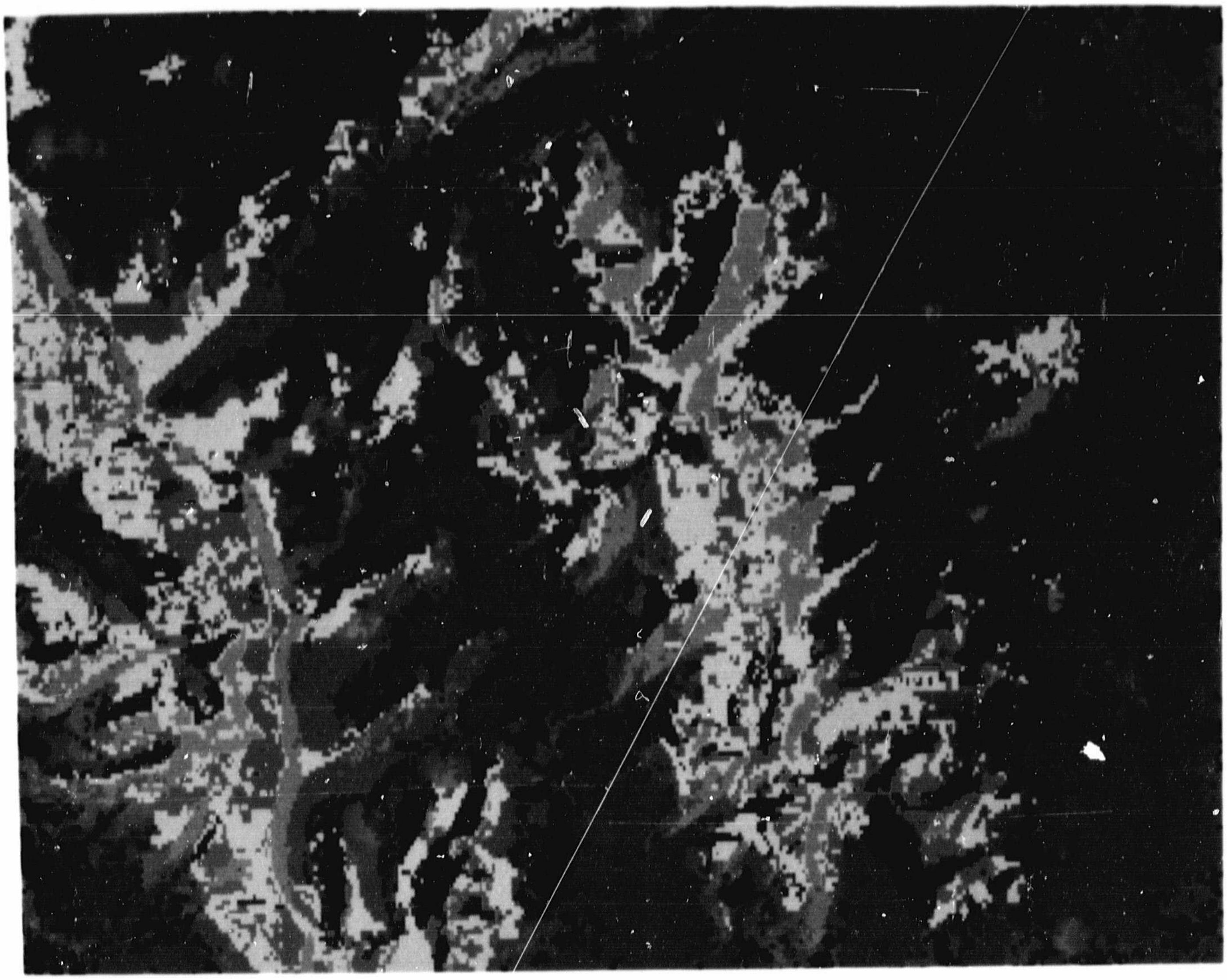
*Percent composition calculated from a grid overlay on the thematic map (See METHODS). Note: The Temperate Zone Complexes composed 55.5% of the Slategoat Study Area.

Fig. 42 Third generation computer thematic map of vegetation complexes in the Slategoat Study Area.

Differences between second and third generation maps can be noted by refering to Fig. 33 and by comparing summary statistics. The composition of the vegetation complexes appear in Table 41. For greater detail of ground cover and understory species see Tables 18, 20, 22, 24, 25, 26, 28, and 29. Note the long linear rock formation on the left side of the map (west). This is a 1000 to 1600 (304 to 488m) sheer limestone cliff known as the "Chinese Wall." This abrupt change in altitude can be interpreted from the color code. The light blue color-encoded Alpine Meadow Complex at 7600 feet (2316m) and above is separated by the linear pink color-encoded rock wall from the gray-blue encoded Temperate Parkland Complex below 7000 feet (2134m). The massive rocky peak in the upper mid-section of the map is Slategoat mountain, 8878 feet (2706m).

Key To Color-Encoded Themes

Vegetation Complexes	Percent Area
Light blue = Alpine Meadow	5.26
Gold = Vegetated Rock	3.03
Pink = Rock I - Limestone	5.49
Red = Rock II - Shaded talus slopes and Argillite	4.44
Light green = Xeric Pinus Albicaulis Forest	4.14
Dark green = Mesic Abies Abies Lasiocarpa/ Pinus Albicaulis Forest	9.32
Gray = Subalpine Parkland	8.80
Dark purple = Xeric Abies Lasiocarpa/ Pseudotsuga Menziesii Forest	9.86
Violet = Mixed Coniferous Forest	33.78
Gray-blue = Temperate Parkland	11.65
Gold-brown = Carex-Salix Marsh	.17
Cream = Equisetum Seepage	.35
Light brown = SCREE	3.39
Unclassified	.38
TOTAL	100.06



Danaher

Over 93% of the Danaher area (Fig. 43) lay within the temperate zone. Table 42 described the vegetation complexes of the zone. Both the Slategoat and Danaher maps can be interpreted by referencing the color codes against Tables 41 and 42, respectively.

Correlation Between Percent Composition of Vegetation Complexes in the Primary Study Area with Those of Computer Extrapolated Areas

The data so far presented show that two of the three criteria established for successful multispectral mapping have been met. Spectral classes have corresponded consistently with ground truth data and they have corresponded with quantitative vegetation descriptions based on ecological principals. The final criterion, that they correspond with vegetation descriptions for geographic areas of extrapolation, was tested by comparing the vegetation of the primary study area with that of the extrapolated areas.

As discussed under METHODS, the computer maps for the secondary areas were first computer extrapolated from the spectral values of the primary area; then the vegetation complexes of these areas were ground mapped

Table 42 Description of vegetation complexes representing a spectral classification for the third generation computer map of the Danaher Study Area.

TEMPERATE CLIMATIC ZONE (<7000')

Vegetation Complex (Class)	Percent Area (Acres)	Description and Composition by Forest Habitat Types or by Ecological Landtypes	Occurrence	Percent Occurrence (Composition)*
Subcomplex IXA: XERIC ABIES LASIOCARPA FOREST; predom. E, SE, S, SW exposures; light canopy cover (15-35%).	11.61	Climax Vegetation: Abies lasiocarpa		
		691 Abies lasiocarpa/Xerophyllum tenax-Vaccinium globulare	44	58
		692 Abies lasiocarpa/Xerophyllum tenax-Vaccinium scoparium	20	26
		010 SCREE	4	5
		650 Abies lasiocarpa/Calamagrostis canadensis	4	5
		630 Abies lasiocarpa/Galium triflorum	4	5
		Total	76	99
Subcomplex IXB: XERIC PSEUDOTSUGA MENZIESII FOREST; predom. E, SE, S, SW exposures; light canopy cover (15-35%).		Climax Vegetation: Pseudotsuga menziesii		
		323 Pseudotsuga menziesii/Calamagrostis rubescens-Calamagrostis rubescens	80	71
		321 Pseudotsuga menziesii/Calamagrostis rubescens-Agropyron spicatum	16	14
		010 SCREE	8	7
		270 Pseudotsuga menziesii/Xerophyllum tenax	8	7
		Total	112	99
Complex X: MIXED CONIFEROUS FOREST; predom. NE, N, NW, W, exposures; heavy canopy cover (35%).	65.00	Climax Vegetation: Abies lasiocarpa or Pseudotsuga menziesii		
		691 Abies lasiocarpa/Xerophyllum tenax-Vaccinium globulare	168	28
		323 Pseudotsuga menziesii/Calamagrostis rubescens-Calamagrostis rubescens	88	15
		670 Abies lasiocarpa/Menziesia ferruginea	64	11
		660 Abies lasiocarpa/Linnaea borealis	56	9
		690 Abies lasiocarpa/Xerophyllum tenax	40	7

*Percent composition of vegetation complexes was calculated employing the grid overlay with the third generation computer map (See METHODS).

Table 42 Continued.

Vegetation Complex (Class)	Percent Area (Acres)	Description and Composition by Forest Habitat Types or by Ecological Landtypes	Occurrence	Percent Occurrence (Composition)*
Complex X (Continued);		270 Pseudotsuga menziesii/Xerophyllum tenax	32	5
		730 Abies lasiocarpa/Vaccinium scoparium	28	4
		410 Picea spp./Equisetum arvense	28	4
		640 Abies lasiocarpa/Vaccinium caespitosum	24	4
		692 Abies lasiocarpa/Xerophyllum tenax-Vaccinium scoparium	20	3
		930 Pinus contorta/Linnaea borealis	16	3
		920 Pinus contorta/Vaccinium caespitosum	12	2
		321 Pseudotsuga menziesii/Calamagrostis rubescens-Agropyron spicatum	8	1
		630 Abies lasiocarpa/Galium triflorum	8	1
		322 Pseudotsuga menziesii/Calamagrostis rubescens-Arctostaphylos uva-ursi	4	1
		450 Picea spp./Vaccinium caespitosum	4	1
		312 Pseudotsuga menziesii/Symphoricarpos albus-Calamagrostis rubescens	4	1
		642 Abies lasiocarpa/Vaccinium caespitosum Calamagrostis canadensis	4	1
		Total	608	101
Complex XI: TEMPERATE PARKLAND	11.36	Climax Vegetation: Festuca spp., Abies lasiocarpa, Picea spp., Pseudotsuga menziesii, Pinus contorta		
		Xeric grass-shrublands	72	82
		SCREE	16	18
		Xeric to mesic seral forest stages (burns)	0	0
		Total	88	100
Complex XII: CAREX-SALIX MARSH	4.04	Carex spp., Betula glandulosa, Salix spp.	37	100
Complex XIII: SCREE(grass-forb)	0.90	Festuca spp. Carex spp.	-	-

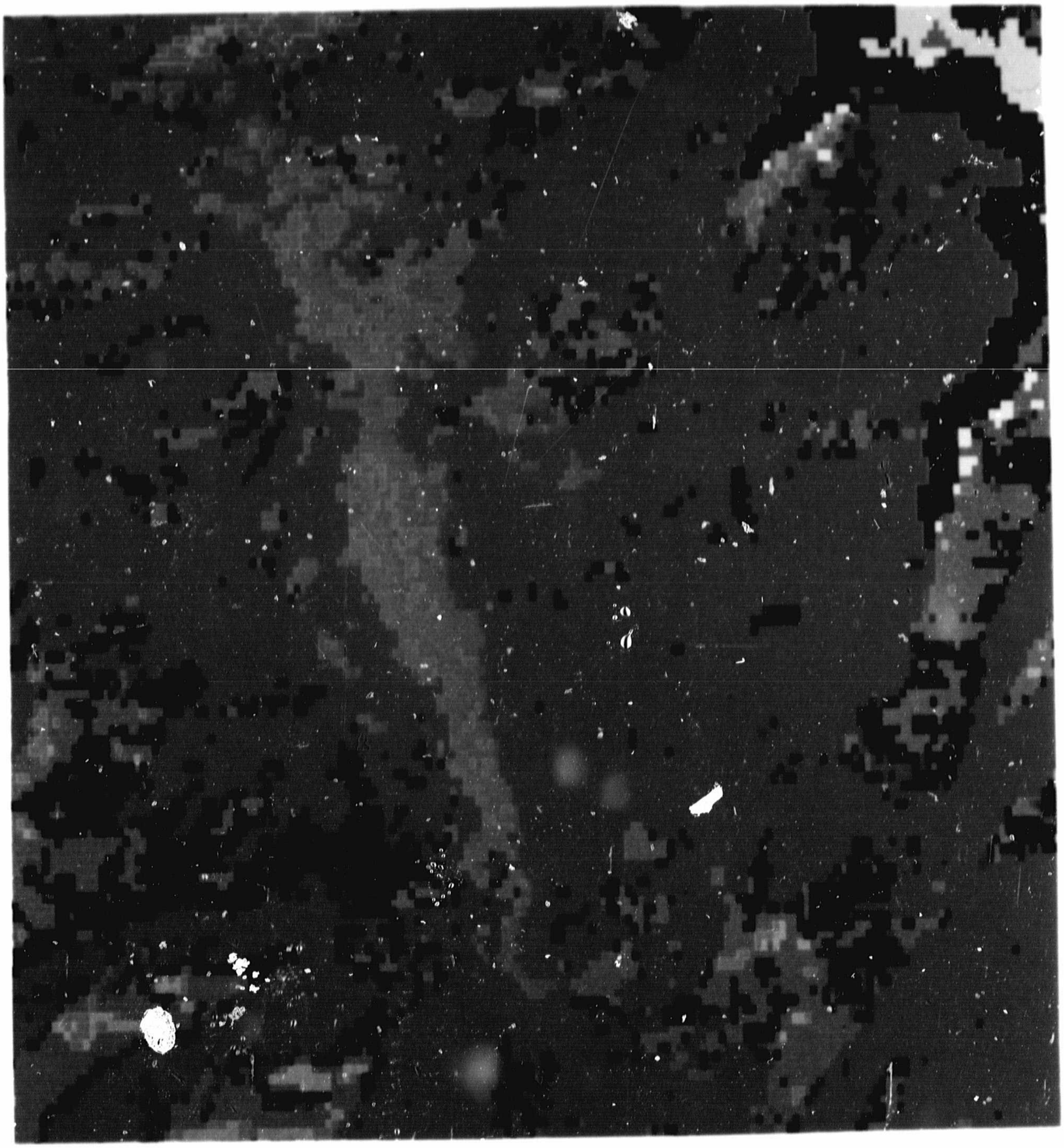
Note: Alpine vegetation complexes totaled less than 2% and Subalpine Complexes totaled 4% of the Danaher study area.

Fig. 43 Third generation computer thematic map of vegetation complexes in the Danaher Study Area.

The Danaher lies largely within the temperate zone (below 7000 feet) (2134m). For detail of vegetation complexes see Table 42. The 854 acre (345.6ha) marsh (mid map) was delineated with a signature polygon. Spectral signatures for it and for the Xeric Abies Lasiocarpa/ Pseudotsuga Menziesii Forest Complex and SCREE (color codes dark purple and light brown, respectively) were identical.

Key To Color Encoded Themes

Vegetation Complexes	Percent Area
Light blue = Alpine Meadow	.05
Gold = Vegetated Rock	.00
Pink = Rock I - Limestone	.61
Red = Rock II-Shaded talus slopes and Argillite	.67
Light green = Xeric Pinus Albicaulis Forest	.30
Dark green = Mesic Abies Lasiocarpa/ Pinus Albicaulis Forest	3.77
Gray = Subalpine Parkland	.18
Dark purple = Xeric Abies Lasiocarpa/ Pseudotsuga Menziesii Forest	11.61
Violet = Mixed Coniferous Forest	65.00
Gray-blue = Temperate Parkland	11.36
Gold-brown = Carex-Salix Marsh	4.04
Cream = Equisetum Seepage	.00
Light brown = SCREE	.90
Unclassified	1.56
TOTAL	100.05



and described. The vegetation complexes for the primary and for the secondary extrapolated areas are compared in Table 43. In evaluating the vegetation comparisons of the primary with the extrapolated areas, it must be recognized that a considerable range in vegetation composition can normally be expected within vegetation types from area to area. Table 43 compares the percent vegetation composition of ELUs, ELTs, and HTs found in each of the complexes displayed on maps - Figs. 29, 42, and 43. For convenience of graphing and comparison, I combined some of the ecological land units of the alpine zone. These were different landforms that supported similar vegetation. For Complex I (Fig. 44) the Alpine Meadow Krummholz, Slab Rock Krummholz, and the Slab Rock Steps (Krummholz) were combined. Complex II combined the Glacial Cirque Basin and Mountain Massif. This consolidation of data did not alter the validity of my comparisons.

I found that the major vegetation components characterizing each complex of the primary area were also present in those same complexes of the extrapolated areas. Also the various components were quantitatively in close agreement. This is graphically presented in Figs. 44 and 45 where three major components of each of 11 complexes are

Table 43 Comparison of vegetation complexes representing a spectral classification for the third generation computer maps of the primary and secondary study areas.

ALPINE CLIMATIC ZONE (>7600') - SCAPEGOAT AND SLATEGOAT

Vegetation Complex (Class)	Percent Area	Description and Composition by Ecological Land Units	Percent Composition* Scapegoat	Slategoat
Complex I: ALPINE MEADOW	7.7	Climax Vegetation: Carex spp.		
		Alpine Meadow Krummholz**	72	83
		Alpine Meadow	25	15
		Vegetated Talus	3	2
		Total	100	100
Complex II: VEGETATED ROCK	5.0	Climax Vegetation: Dryas octopetala		
		Mountain Massif & Glacial Cirque Basin	47	58
		Semi-vegetated Talus	23	12
		Fellfield	14	21
		Bare Talus	11	4
		Parent Rock-Limestone	5	0
		Alpine Meadow Krummholz	0	5
		Total	100	100
Complex III: BARE ROCK I	6.4	Climax Vegetation: Lichens		
		Parent Rock-Limestone	45	53
		Bare Talus	33	43
		Semi-vegetated Talus	0	4
		Snowfield and Snowfield Sinks	7	0
		Fellfield	3	0
		Total	100	100
Complex IV: BARE ROCK II	5.0	Climax Vegetation: Lichens		
		Bare Talus in shadow	71	40
		Parent Rock-Argillite	29	60
		Total	100	100

*Percent composition of vegetation complexes was calculated employing grid overlay with the third generation computer map (See METHODS).
**Alpine Meadow Krummholz includes Slab Rock Steps and Slab Rock Krummholz.

Table 43 Continued.

SUBALPINE CLIMATIC ZONE (7600'-7000') - SCAPEGOAT AND SLATEGOAT

Vegetation Complex (Class)	Percent Area Scapegoat-Slategoat	Description and Composition by Forest Habitat Types or by Ecological Landtypes	Percent Composition Scapegoat	Percent Composition Slategoat
Complex V: XERIC PINUS ALBICAULIS FOREST; predom. E, SE, S, SW exposures; light canopy cover (15-35%).	6.8	Climax Vegetation: Abies lasiocarpa		
		831 Abies lasiocarpa/Luzula-hitchcockii-Vaccinium scoparium	42	6
		820 Abies lasiocarpa(Pinus albicaulis)/Vaccinium scoparium	22	
		850 Pinus albicaulis-Abies lasiocarpa	14	7
		010 SCREE	7	2
		832 Abies lasiocarpa/Luzula hitchcockii-Menziesia ferruginea	5	
		692 Abies lasiocarpa/Xerophyllum tenax-Vaccinium scoparium	4	
		691 Abies lasiocarpa/Xerophyllum tenax-Vaccinium globulare	3	
		860 Larix lyallii-Abies lasiocarpa	3	
		Total	100	100
Complex VI: MESIC ABIES LASIOCARPA/PINUS ALBICAULIS FOREST; predom. NE, N, NW, W exposures; moderate to heavy canopy cover. (35%).	16.4	Climax Vegetation: Abies lasiocarpa		
		831 Abies lasiocarpa/Luzula hitchcockii-Vaccinium scoparium	37	44
		832 Abies lasiocarpa/Luzula hitchcockii-Menziesia ferruginea	19	6
		820 Abies lasiocarpa(Pinus albicaulis)/Vaccinium scoparium	12	36
		670 Abies lasiocarpa/Menziesia ferruginea	11	
		850 Pinus albicaulis-Abies lasiocarpa	5	8
		860 Larix lyallii-Abies lasiocarpa	5	6
		691 Abies lasiocarpa/Xerophyllum tenax-Vaccinium globulare	5	
		690 Abies lasiocarpa/Xerophyllum tenax	3	
		692 Abies lasiocarpa/Xerophyllum tenax-Vaccinium scoparium	2	

Table 43 Continued.

Vegetation Complex (Class	Percent Area Scapegoat-Slategoat	Description and Composition by Forest Habitat Types or by Ecological Landtypes	Percent Composition Scapegoat	Percent Composition Slategoat
Complex VI Continued:		650 Abies lasiocarpa/Calamagrostis canadensis	1	
		Total	100	100
Complex VII: SUBALPINE PARKLAND	10.6	Climax Vegetation: Festuca spp., Abies lasiocarpa		
		SCREE	42	8
		Xeric-mesic seral forest stages (burns)	32	31
		Xeric subalpine grass-shrublands	26	61
		Total	100	100
Complex VIII: EQUISETUM SEEPAGE	.4	Equisetum arvense, pedicularis groenlandica	1	100
Complex XIII SCREE (grass-shrub)	3.3	Festuca idahoensis, Carex spp.	-	-

Table 43 Continued

TEMPERATE CLIMATIC ZONE (<7000') - SCAPEGOAT AND DANAHER

Vegetation Complex (Class)	Percent Area	Description and Composition by Forest Habitat Types or by Ecological Landtypes	Percent Composition Scapegoat	Percent Composition Danaher
Subcomplex IXA: XERIC ABIES LASIOCARPA FOREST;predom. E, SE, S, SW exposures; light canopy cover (15-35%)	5.4	Climax Vegetation: Abies lasiocarpa		
		691 Abies lasiocarpa/Xerophyllum tenax-Vaccinium globulare	42	8
		692 Abies lasiocarpa/Xerophyllum tenax-Vaccinium scoparium	38	6
		820 Abies lasiocarpa(Pinus albicaulis)/Vaccinium scoparium	7	
		670 Abies lasiocarpa/Menziesia ferruginea	5	
		010 SCREE	4	5
		750 Abies lasiocarpa/Calamagrostis rubescens	3	
		650 Abies lasiocarpa/Calamagrostis canadensis	1	5
		630 Abies lasiocarpa/Galium triflorum		5
		Total	100	100
Subcomplex IXB: XERIC PSEUDOTSUGA MENZIESII FOREST; predom. E, SE, S, SW exposures; light canopy (15-35%)		Climax Vegetation: Pseudotsuga menziesii		
		320 Pseudotsuga menziesii/Calamagrostis rubescens	52	71
		360 Pseudotsuga menziesii/Juniperus communis	37	-
		010 SCREE	11	7
		321 Pseudotsuga menziesii/Calamagrostis rubescens-Agropyron spicatum		15
		270 Pseudotsuga menziesii/Xerophyllum tenax		7
		Total	100	100
Complex X: MIXED CONIFEROUS TEMPERATE FOREST; predom. N, NW, NE exposures; heavy canopy cover (35%).	26.2	Climax Vegetation: Abies lasiocarpa or Pseudotsuga menziesii or Picea spp.		
		670 Abies lasiocarpa/Menziesia ferruginea	43	11
		691 Abies lasiocarpa/Xerophyllum tenax-Vaccinium globulare	27	28

Table 43 Continued.

Vegetation Complex (Class)	Percent Area	Description and Composition by Forest Habitat Types or by Ecological Landtypes	Scapegoat	Danaher
		692 Abies lasiocarpa/Xerophyllum tenax-Vaccinium scoparium	16	3
		750 Abies lasiocarpa/Calamagrostis rubescens	4	
		690 Abies lasiocarpa/Xerophyllum tenax	3	6
		650 Abies lasiocarpa/Calamagrostis canadensis	2	
		820 Abies lasiocarpa(Pinus albicaulis)/Vaccinium scoparium	2	
		360 Pseudotsuga menziesii-Juniperus communis	1	
		320 Pseudotsuga menziesii-Calamagrostis rubescens	1	
		780 Abies lasiocarpa/Arnica cordifolia	1	
		660 Abies lasiocarpa/Linnaea borealis	1	14
		323 Pseudotsuga menziesii/Calamagrostis rubescens-Calamagrostis rubescens		22
		730 Abies lasiocarpa/Vaccinium scoparium		7
		270 Pseudotsuga menziesii/Xerophyllum tenax		8
		410 Picea spp./Equisetum arvense		7
		640 Abies lasiocarpa/Vaccinium caespitosum		6
		930 Pinus contorta/Linnaea borealis		4
		321 Pseudotsuga menziesii/Calamagrostis rubescens-Agropyron spicatum		2
		920 Pinus contorta/Vaccinium caespitosum		3
		630 Abies lasiocarpa/Galium triflorum		2
		322 Pseudotsuga menziesii/Calamagrostis rubescens-Arctostaphylos uva-ursi		1
		450 Picea spp./Vaccinium caespitosum		1
		312 Pseudotsuga menziesii/Symphoricarpos albus-Calamagrostis rubescens		1
		642 Abies lasiocarpa/Vaccinium caespitosum-Calamagrostis canadensis		1
		Total	100	100

Table 43 Continued.

Vegetation Complex (Class	Percent Area	Description and Composition by Forest Habitat Types or by Ecological Landtypes	Percent Composition Scapegoat	Percent Composition Danaher
Complex XI: TEMPERATE PARKLAND COMPLEX	5.2	Climax Vegetation: Festuca spp., Abies lasiocarpa, Picea spp., Pseudotsuga menziesii, Pinus contorta		
		Xeric to mesic seral forest stages (burns)	53	-
		Xeric grass-shrublands	24	82
		SCREE	23	18
		Total	100	100
Complex XII: CAREX-SALIX MARSH	.9	Carex spp., Betula glandulosa, Salix spp.	100	100

Fig. 44 Graph comparing major vegetation types and land-vegetation units occurring within seven vegetation complexes of the alpine and sub-alpine zones of the Scapegoat and Slategoat Study Areas.

Key to Fig. 44

Complex I
- Krummholz (3 units)
- Alpine Meadow
- Vegetated Talus

Complex II
- Glacial Cirque Basin and Mountain Massif (2 units)
- Semi-vegetated Talus
- Fellfield

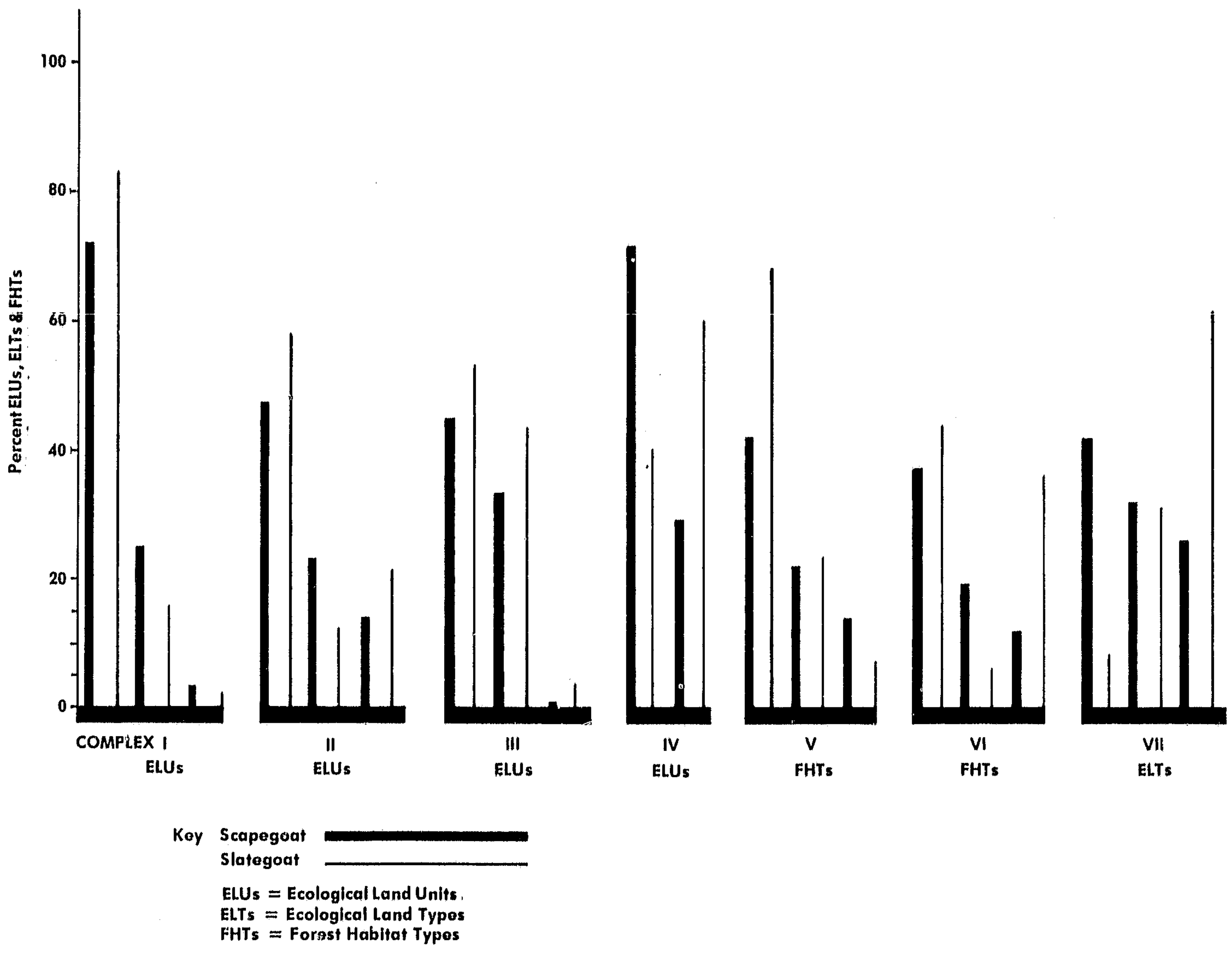
Complex III
- Parent Rock-Limestone (Lichens)
- Bare Talus
- Fellfield

Complex IV
- Bare Talus in Shadow (Lichens)
- Parent Rock (Lichens)

Complex V
- Forest habitat types
  - 831
  - 820
  - 850

Complex VI
- Forest habitat types
  - 831
  - 832
  - 820

Complex VII
- SCREE with trees
- Xeric-mesic Seral Forests Stages (Burns)
- Grass-Shrublands



100
80
60
40
20
0
Percent ELUs, ELTs & FHTs
COMPLEX I
ELUs
II
ELUs
III
ELUs
IV
ELUs
V
FHTs
VI
FHTs
VII
ELTs
Key Scapegoat
Slategoat
ELUs = Ecological Land Units
ELTs = Ecological Land Types
FHTs = Forest Habitat Types

Fig. 45 Graph comparing major vegetation types and land vegetation units occurring within four vegetation complexes of the temperate zone of the Scapegoat and Danaher Study Areas.

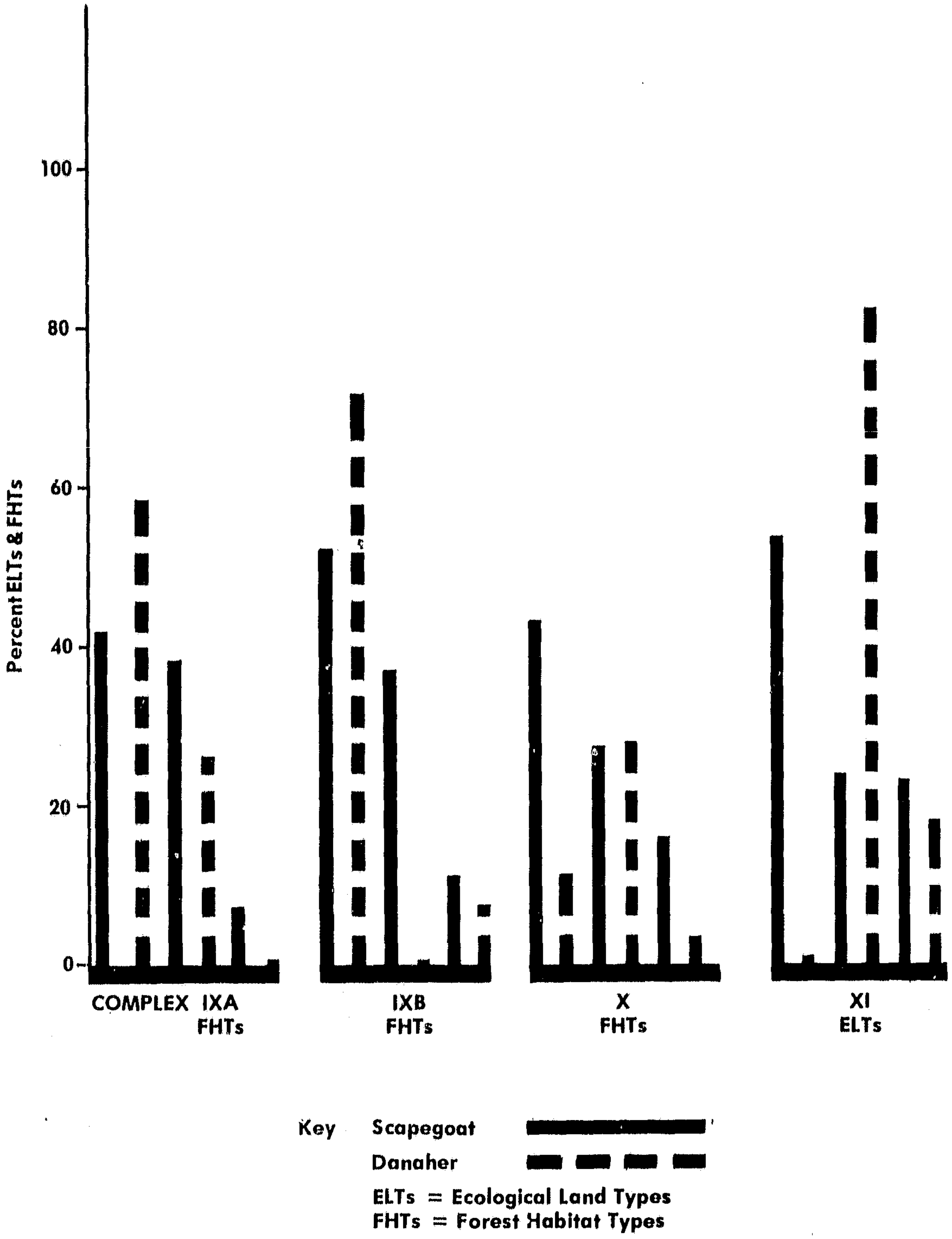
Key to Fig. 45

Complex IX A
- Forest habitat types
  - 691
  - 692
  - 820

Complex IX B
- Forest habitat types
  - 320
  - 360
  - 010 SCREE

Complex X
- Forest habitat types
  - 670
  - 691
  - 692

Complex XI
- Xeric-Mesic Seral Forest Stages (Burns)
- SCREE
- Grass-shrublands


Percent ELTs & FHTs
100
80
60
40
20
0
COMPLEX IXA
FHTs
IXB
FHTs
X
FHTs
XI
ELTs
Key Scapegoat
Danaher
ELTs = Ecological Land Types
FHTs = Forest Habitat Types

compared. Two minor complexes, the Equisetum Seepage and the Carex-Salix Marsh, were omitted from the comparisons. The great vegetative similarity, between the various vegetation complexes of the areas compared, far outweighed the dissimilarity. I considered this as conclusive evidence that the spectral values, elevationally grouped and computer-extrapolated, consistently represented ecologically similar vegetation for the same vegetation complexes in different geographical areas.

The vegetation types of Danaher were comparable to those of the temperate zone of Scapegoat (Fig. 45). All major vegetation components of the primary area (ELUs, ELTs, and HTs) were found, by on-the-ground sampling, also in the areas of extrapolation. From this I concluded that the spectral classes and the signature polygons represented similar vegetation types within each of the three study areas. This was true qualitatively and to some extent quantitatively. Therefore, computer extrapolation of vegetation complexes from multi-spectral imagery had proved feasible and accurate. Moreover, any signature or signature polygon when extrapolated within a well-defined ecosystem should represent similar vegetation. This implied that the vegetation of a large geographic area can be accurately computer mapped by extrapolation

from a LANDSAT scene.

Description of Vegetation Complexes in terms of Bear Food Plants

The vegetation classification system I developed from multispectral imagery with computer assistance employs maps and statistical readouts. It can be useful to land and wildlife managers if the classification can be interpreted in terms of specific resources. For the grizzly bear this means relating bear food plants to the vegetation complexes and then rating the complexes using the system developed in Sections I and II. Estimates of the importance of the various vegetation complexes are then possible.

In Section I we described the abundance of grizzly bear food plants by ecological land units, landtypes, and forest habitat types. To facilitate converting this information to the new eco-spectral classification of vegetation complexes, I first summarized the food plant abundance data as shown in Figs. 46 and 47; then rearranged them to conform to the computer-derived multispectral classification.

Percent Abundance of Food Plants

The percent abundance of specific bear food plants,

238

Fig. 46 KEY TO ECOLOGICAL LAND UNITS, LANDTYPES AND FOREST HABITAT TYPES

AM — Alpine Meadow
AMK — Alpine Meadow Krummholz
SRK — Slab Rock Krummholz
SRS — Slab Rock Steps
VT — Vegetated Talus
GCB — Glacial Cirque Basin
MM — Mountain Massif
SVT — Semi-vegetated Talus
FF — Fellfield

Subalpine
SSB — Seral Stages [Burns]
WFB — Wet Forb Grasslands
DFG — Dry Forb Grasslands
SS — Snowslides
~~RG — Ridgetop Glades~~
831 — Abies lasiocarpa/Luzula hitchcockii—Vaccinium scoparium
820 — Abies lasiocarpa [Pinus albicaulis]/Vaccinium scoparium
832 — Abies lasiocarpa/Luzula hitchcockii—Menziesia ferruginea
850 — Pinus albicaulis-Abies lasiocarpa

Temperate
SSB — Seral Stages [Burns]
WFG — Wet Forb Grasslands
DFG — Dry Forb Grasslands
010 — SCREE
691 — Abies lasiocarpa/Xerophyllum tenax-Vaccinium globulare
692 — Abies lasiocarpa/Xerophyllum tenax-Vaccinium scoparium
670 — Abies lasiocarpa/Menziesia ferruginea
320 — Pseudotsuga menziesii/Calamagrostis rubescens

SUMMARY OF TOTAL GRIZZLY BEAR FOOD PLANT ABUNDANCE BY ECOLOGICAL LAND UNITS, LANDTYPES, AND FOREST HABITAT TYPES

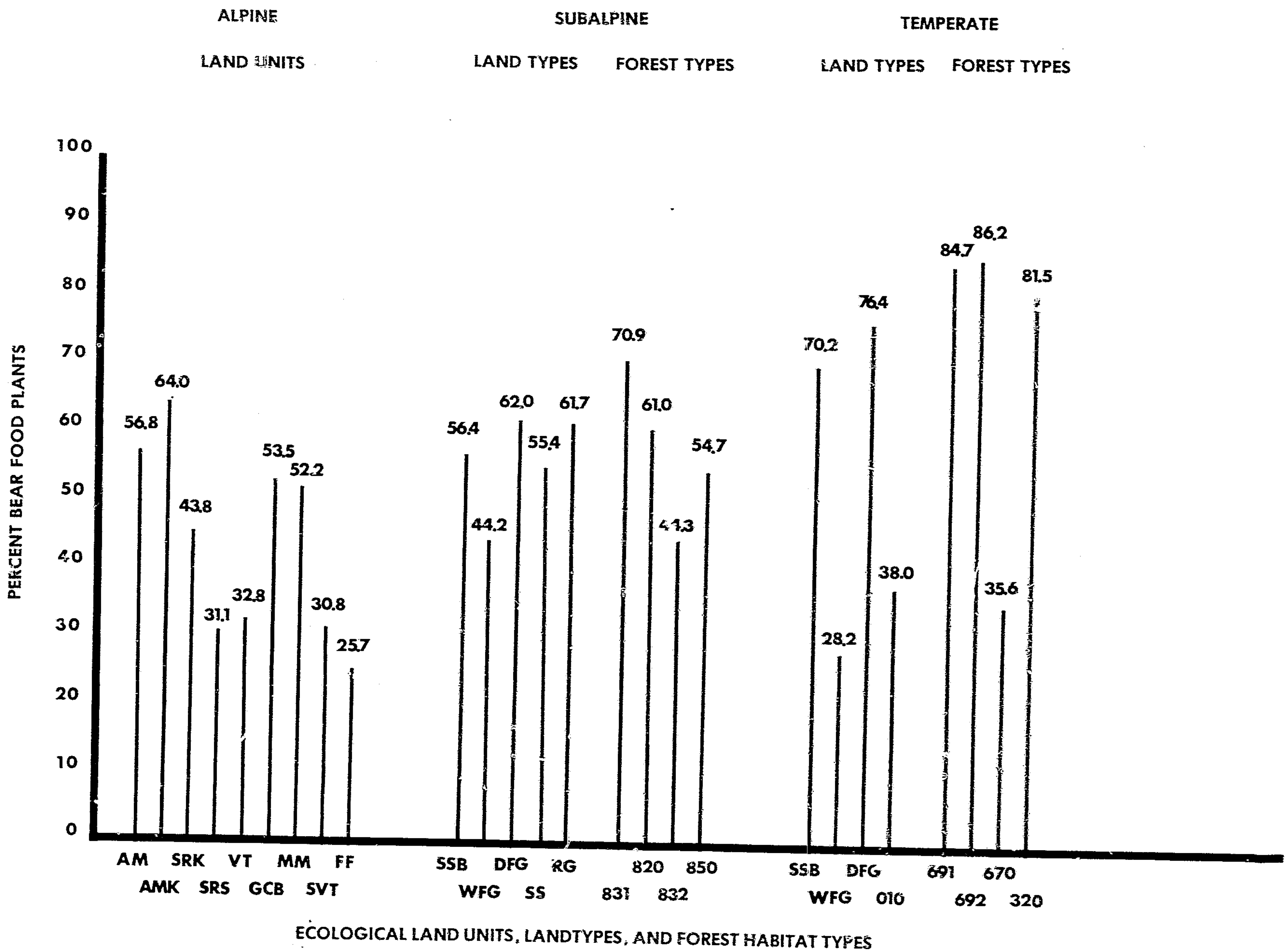


Fig. 47 Grizzly bear food plant abundance values presented here and in Fig. 46 show the percentages of total and selected food plants recorded for each ecological land unit, landtype, and forest habitat type of Scapegoat. These values can be related directly to the ground vegetation map, Fig. 37. Data regrouped to conform to vegetation complexes are presented in Table 45 and Figs. 48 and 49. They can be related directly to the computer map of Scapegoat, Fig. 29.

SUMMARY OF SELECTED GRIZZLY BEAR FOOD PLANT ABUNDANCE BY ECOLOGICAL LAND UNITS, LANDTYPES, AND FOREST HABITAT TYPES

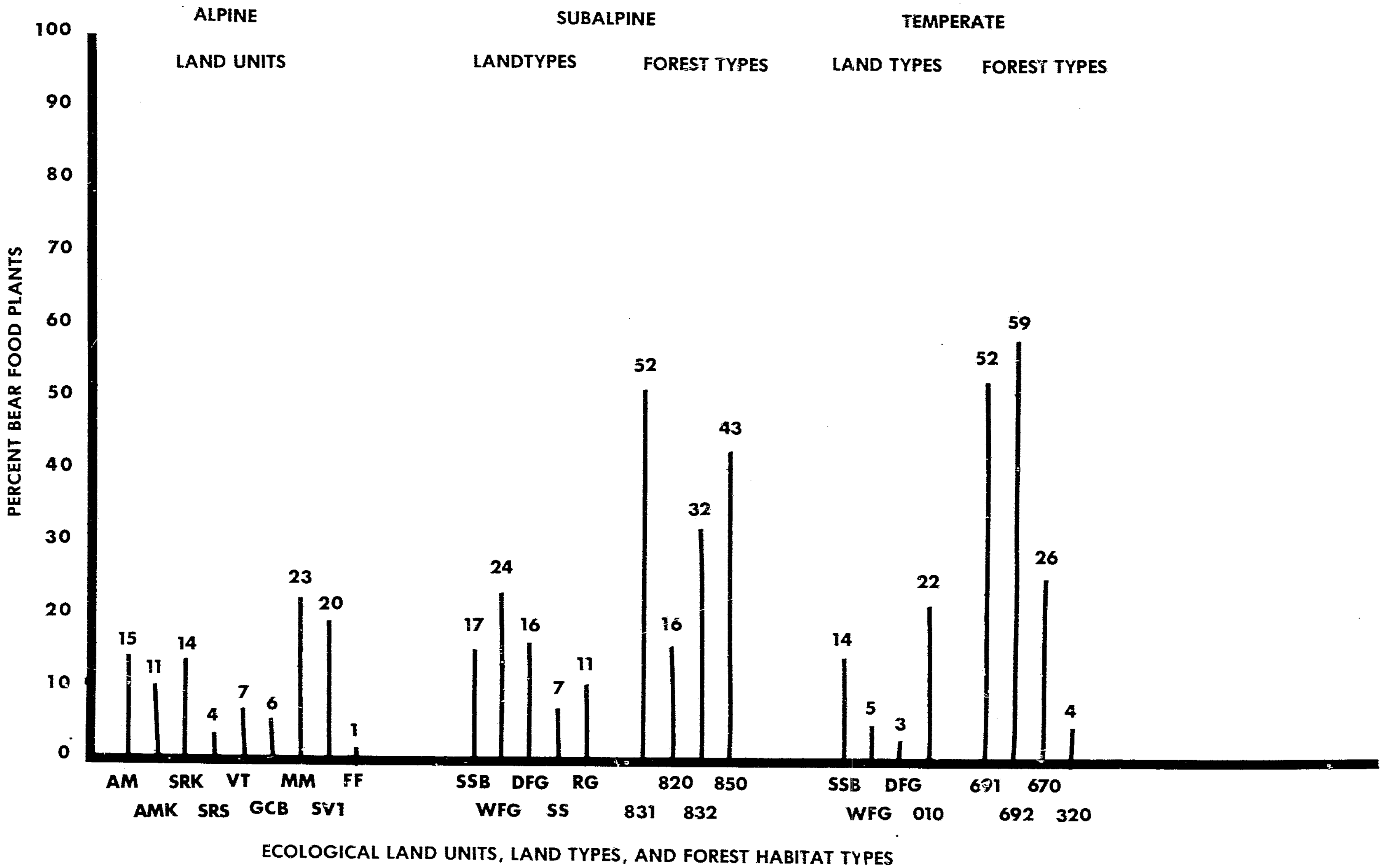
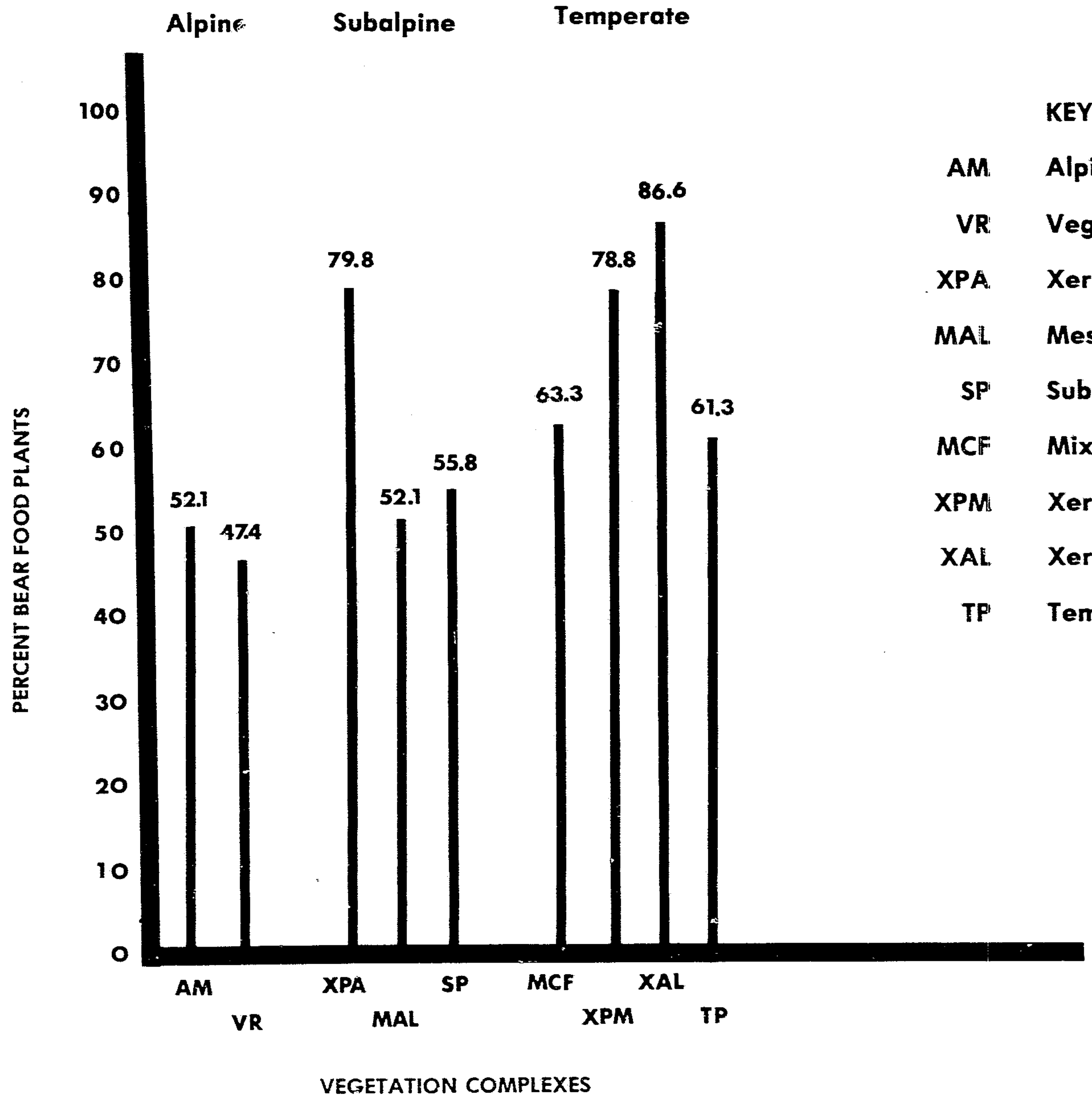


Fig. 48 shows the food plant abundance for 9 vegetation complexes, extending through 3 climatic zones. Relating the graph directly to the corresponding vegetation complexes displayed in Figs. 29, 42, and 43 reveals the distribution of the plant food resource. For example, the Alpine Meadow Complex with a food plant abundance of 52.1% is represented in Figs. 29, 42, and 43 in light blue. The Vegetated Rock Complex with a value of 47.4% is displayed in gold, the Xeric Pinus Albicaulis Forest Complex (79.8%) in light green and so forth for the other color-encoded complexes.

SUMMARY OF TOTAL GRIZZLY BEAR FOOD PLANT ABUNDANCE BY VEGETATION COMPLEXES

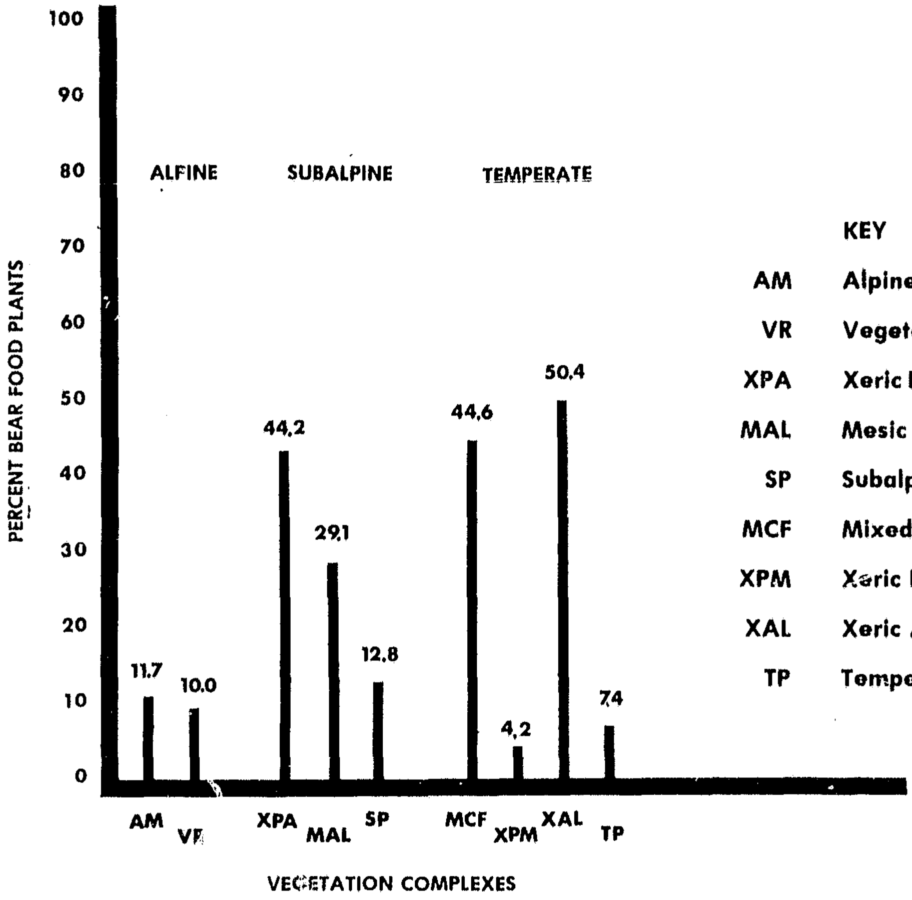


KEY

AM	Alpine Meadow Complex
VR	Vegetated Rock Complex
XPA	Xeric Pinus Albicaulis Forest Complex
MAL	Mesic Abies Lasiocarpa Forest Complex
SP	Subalpine Parkland Complex
MCF	Mixed Coniferous Forest Complex
XPM	Xeric Pseudotsuga Menziesii Forest Complex
XAL	Xeric Abies Lasiocarpa Forest Complex
TP	Temperate Parkland Complex

Fig. 49 summarizes the food plant abundance of selected grizzly bear foods. The graph can be interpreted as explained for Fig. 48.

SUMMARY OF GRIZZLY BEAR FOOD PLANT ABUNDANCE BY VEGETATION COMPLEXES
SELECTED FOODS



KEY

AM	Alpine Meadow Complex
VR	Vegetated Rock Complex
XPA	Xeric Pinus Albicaulis Forest Complex
MAL	Mesic Abies Lasiocarpa Forest Complex
SP	Subalpine Parkland Complex
MCF	Mixed Coniferous Forest Complex
XPM	Xeric Pseudotsuga Menziesii Forest Complex
XAL	Xeric Abies Lasiocarpa Forest Complex
TP	Temperate Parkland Complex

as re-arranged by complexes, is presented in Table 45. This has been done so the food plant abundance values can be compared within and between the various (9) vegetation complexes that comprise the spectral reflectance classification. For example, within the Alpine Meadow Complex (I), 14 food plants comprised 52% of the total vegetation sampled, with percentages as shown in Table 45. Within the Vegetated Rock Complex, the food plant abundance was 47% and so on for each vegetation complex. Figure 48 shows that, potentially, bear food plants were most abundant in the Xeric Pinus Albicaulis, the Xeric Pseudotsuga Menziesii, and the Xeric Abies Lasiocarpa Forest Complexes. The specific plants that occurred abundantly in those complexes are listed in Table 45.

The abundance of potential bear food plants drops sharply when only the selected ones are considered (Fig. 49). However, the values remained relative with two exceptions; the value for the Xeric Pseudotsuga Menziesii Forest Complex dropped while that for the Mixed Coniferous Forest Complex rose. The values designated for each of the nine complexes indicate their relative importance to the grizzly bear.

Area Percentages for the Vegetation Complexes

Each vegetation complex is shown as an area percentage of Scapegoat in Table 46. The Alpine Meadow Complex comprised 7.88%, the Vegetated Rock Complex 5.81%, the Xeric Pinus Albicaulis Forest Complex 8.01% and so on for each of the complexes. Area percentages for the respective vegetation complexes of all three study areas provides useful parameters for evaluating grizzly bear habitat.

Habitat Ratings by Complex

Habitat values, derived by adding the percent abundance value of grizzly bear food plants to the percent area value, are presented in Table 44. The Xeric Abies Lasiocarpa and the Mixed Coniferous Forest Complexes exhibited the highest habitat values with values for the other complexes as shown in Table 44. These values, expressing habitat potential, were then converted to numerical ratings of 1 through 8 with a rating of 1 high. These ratings define the habitat potential of any portion of the computer-generated map of Scapegoat. The same ratings can be applied to the Slategoat and Danaher areas or to any computer-extrapolation of a large but ecologically defined geographic area of the Scapegoat-Bob Marshall Wilderness (Fig. 50).

Table 44 Ha' 'tat Ratings for the Vegetation Complexes of the Scapegoat Study Area.

	VEGETATION COMPLEXES							
	I	II	V	VI	VII	IXA IXB	X	XI
Rating Method	Alpine Meadow	Vegetated Ro'..	Xeric Pinus Albicaulis Forest	Mesic Abies Lasiocarpa/Pinus Albicaulis Forest	Subalpine Parkland	Xeric Abies Lasiocarpa-Pseudotsuga Menziesii Forest	Mixed Coniferous Forest	Temperate Parkland
Percent Habitat	7.88	5.81	8.01	20.25	8.35	6.53	27.01	6.03
Percent Total Bear Food Plants	52.1	47.4	79.7	51.9	55.8	84.1	63.0	61.3
Percent Selected Bear Food Plants	11.7	10.0	44.2	29.1	12.8	27.3	44.6	7.4
Habitat Value (TBFP)	59.98	53.21	87.71	72.15	64.15	90.63	90.01	67.33
Habitat Value (SBFP)	19.58	15.81	52.21	49.35	21.15	33.83	71.61	13.43
Habitat Rating (TBFP)	7	8	3	4	6	1	2	5
Habitat Rating SBFP)	6	7	2	3	5	4	1	8

Ratings 1 through 8 with 1 = highest rating
TBFP = Total Bear Food Plants
SBFP = Selected Bear Food Plants

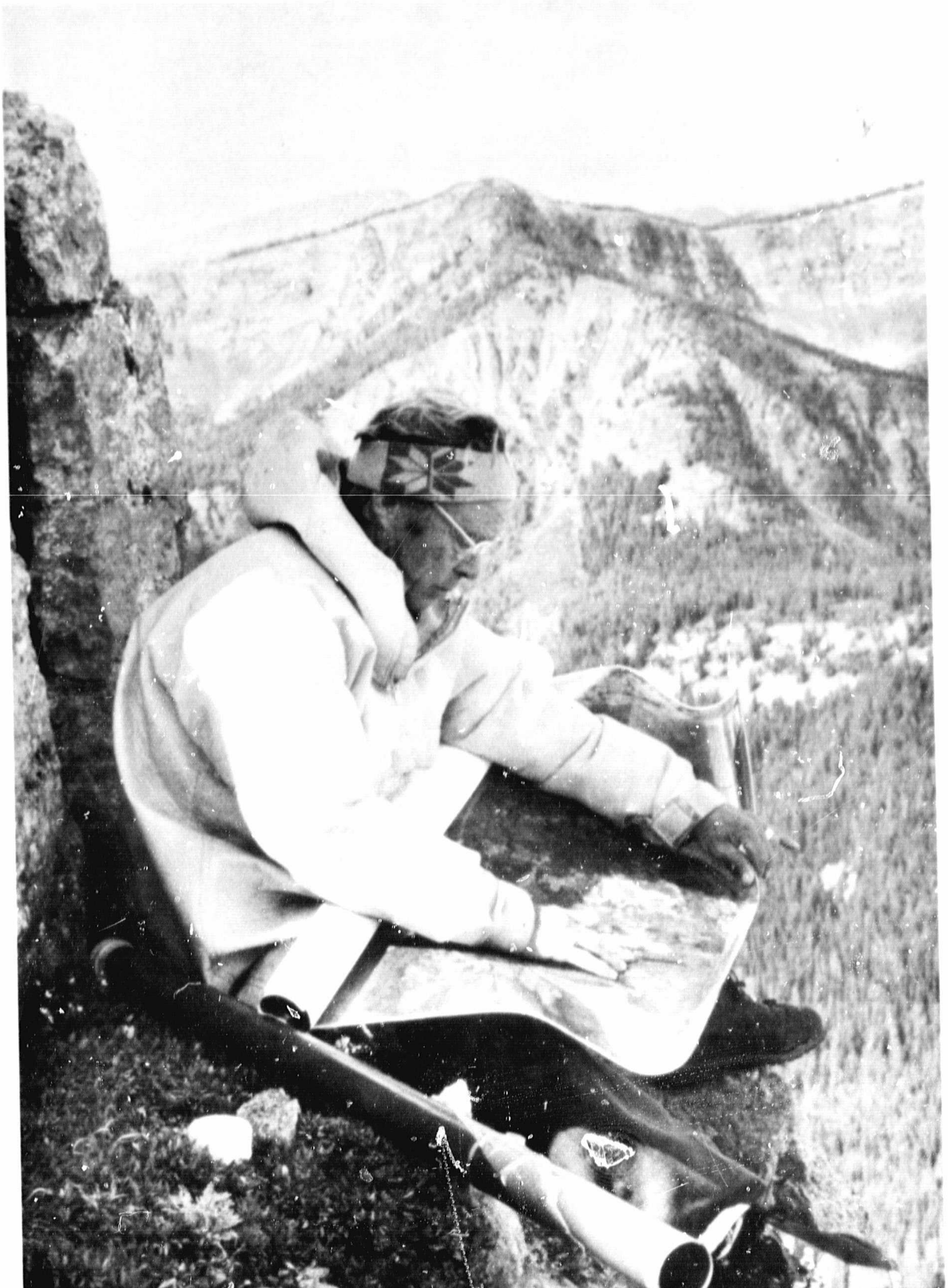
Table 45. Bear food plants found in the Vegetation Complexes of the Ecajegoat Study Area

Bear Food Plants	I Alpine Meadow	II Vegetated Rock	V Xeric Pinus Albicaulis Forest	VI Mesic Abies Lasiocarpa/Pinus Albicaulis Forest	VII Subalpine Parkland	IXA Xeric Abies Lasiocarpa-Pseudotsuga Menziesii Forest: Abies Lasiocarpa Forest	IXB Xeric Abies Lasiocarpa-Pseudotsuga Menziesii Forest: Pseudotsuga Menziesii Forest	X Mixed Coniferous Temperate Forest	XI Temperate Parkland
Graminales									
Carex spp.	20.9	17.3			13.1				[illegible]
Festuca idahoensis	16.0	12.5	T		7.7		.4		7.7
Calamagrostis rubescens			T		1.9	3.1	67.7	.7	.3
Calamagrostis canadensis			T		2.2				
Carex geyeri			5.4	7.6		.8	16.4	1.1	4.9
Melica spectabilis					.1				
Agropyron spicatum							2.4		4.7
Festuca scabrella							.4		16.9
Phleum pratense									3.4
Bromus sp.									1.1
Deschampsia cespitosa									1.0
Poa pratensis									.6
Danthonia spicata									.4
Poa spp.									.3
Phleum alpinum									.1
Gramineae	2.7	3.7			6.0				1.6
Subtotal	39.6	33.5	5.4	7.6	31.0	3.9	77.3	1.8	50.0
Shrubs									
Arctostaphylos uva-ursi	5.0	6.2			.1	T		.3	.6
Vaccinium scoparium	1.5		43.6	28.3	3.2	30.9		32.6	.4
Ribes spp.	.1								
Ribes lacustre		T	T	.1	T	T	T	T	
Vaccinium globulare			.3	.1	.6	18.7		6.4	
Shepherdia canadensis			.3		.5	.8		4.8	.8
Vaccinium myrtillus					.1				
Amelanchier alnifolia					.1		.4		1.4
Lonicera involucrata					.1	T			
Lonicera utahensis						T			.3
Symphoricarpos albus							1.0	.3	.6
Rosa sp.							.4		
Berberis repens					T		T	.1	
Prunus virginiana									.3
Subtotal	6.6		44.2	28.5	4.7	50.4	1.8	44.5	4.4
Forbs									
Hedysarum spp.	1.7								
Polygonum spp.	1.4								
Erythronium grandiflorum	1.2	.2	T	T	1.0		T		
Juncus parryi	.8	3.9			.2				
Lomatium spp.	.6				.6				
Cirsium scariosum	.1		T		.1	T		T	
Claytonia lanceolata	.1	.2	T		.8				
Fragaria virginiana	T	.2	T	.2	1.5	T	1.7	.1	2.5
Claytonia megarhiza		1.2							
Hedysarum sulphurescens		1.0			.1				
Lomatium cous		1.0							
Agoseris spp.		T			T				
Heracleum lanatum		T	T	.3	1.1				
Xerophyllum tenax			30.1	15.2	12.1	32.4		16.6	4.2
Lomatium dissectum			T		.2				
Hedysarum occidentale				.1	.2				
Equisetum arvense					1.2				
Osmorhiza occidentalis					.9			T	
Polygonum bistortoides					.3				
Rubus parviflorus					.1	T	.7		
Angelica dawsonii					T				
Perideridia gairdneri					T				.1
Hieracium spp.					T				.3
Trifolium sp.									.1
Subtotal	5.9	7.7	30.1	15.8	20.4	32.4	2.4	16.7	7.2
Total Bear Food Plants	52.1	47.4	79.7	51.9	55.8	86.7	81.5	63.0	61.3
Other Species	47.9	42.6	20.3	48.1	44.2	13.3	18.5	37.0	38.7
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 46 Third Generation Area Summary of Scapegoat, Slategoat and Danaher.

Complexes	Scapegoat				Slategoat				Danaher			
	Area Pixels	Area Acres	Area Hectares	Area Percent	Area Pixels	Area Acres	Area Hectares	Area Percent	Area Pixels	Area Acres	Area Hectares	Area Percent
Alpine Meadow	3487	3905	1580	7.88	4048	4534	1834	5.26	9	10	4	.05
Vegetated Rock	2567	2875	1163	5.81	2326	2605	1054	3.03	0	0	0	0
Bare Rock I	2053	2299	930	4.64	4221	4728	1912	5.49	129	144	58	.61
Bare Rock II	1551	1737	703	3.51	3411	3820	1545	4.44	141	158	64	.67
Xeric Pinus Albicaulis	3541	3966	1604	8.01	3185	3567	1443	4.14	62	69	28	.30
Mesic Abies Lasiocarpa/ Pinus Albicaulis Forest	8959	10034	4058	20.25	7169	8029	3248	9.32	797	893	361	3.77
Subalpine Parkland	3693	4136	1673	8.35	6766	7578	3065	8.80	37	41	17	.18
Xeric Abies Lasiocarpa / Pseudotsuga Menziesii Forest	2887	3233	1308	6.53	7585	8495	3436	9.86	2455	2750	1112	11.61
Mixed Coniferous Temperate Forest	11951	13385	5414	27.01	25995	29114	11776	33.78	13750	15400	6229	65.30
Temperate Parkland	2663	2983	1206	6.03	8961	10036	4059	11.65	2403	2691	1089	11.36
Carex-Salix Marsh	13	15	6	.03	127	142	58	.17	854	956	387	4.04
Equisetum Seepage	107	120	48	.25	263	295	119	.35	0	0	0	0
SCREE	679	760	308	1.54	2609	2922	1182	3.39	189	212	86	.90
Unclassified	102	115	46	.23	296	332	133	.38	330	371	149	1.56
Total	44253	49563	20047	100.07	76962	86197	34864	100.06	21156	23695	9584	100.05

Fig. 50 Field checking grizzly bear habitat ratings and the distribution of vegetation complexes in the Slategoat Study Area. Grizzly bear food plants recorded and quantified in the primary study area were present in the Slategoat area of extrapolation. The habitat ratings for the vegetation complexes of Scapegoat, Table 44, were directly applicable to these same vegetation complexes in the two areas of extrapolation.



Extrapolation to a Large Geographic Area

An area of approximately 2000 square miles (5180 km^2) can be computer mapped by extrapolation with an accuracy comparable to that shown for the Slategoat and Danaher sites. The area of extrapolation (Fig. 2) lies within the ecosystem described in this and preceeding sections. Beyond the limits of the ecosystem the plant ecology changes. Therefore, the signatures and signature polygons developed for the primary study area are not applicable since they are not represented on the ground by the same type of vegetation. To computer map beyond the prescribed ecosystem, additional ground mapping and vegetation sampling are necessary as well as the development of new signatures. With this accomplished, the LANDSAT imagery may be employed for additional mapping. The significance of the system I have described is that the vegetation of large geographic areas can be computer-mapped with accuracy following initial ground truthing of small representative study sites.

Interpretation and Application of the Computer Mapping System

To facilitate rapid interpretation of the third generation computer maps, (Figs. 29, 42 and 43) I diagramed the zonal distribution of the vegetation complexes, showing diagnostic

vegetation for each complex, (Fig. 51). Thirteen complexes are shown in relation to their respective climatic zones. Diagnostic vegetation for the complexes are not necessarily climatic zone indicators but are rather descriptive of the major vegetation found in each complex within the altitudinal and latitudinal limits of the areas studied. A specific complex can be put in perspective by refering to Fig. 51, and a more complete description obtained by consulting Tables 14, 41, 42 and 43.

Computer-generated area statistics for the thirteen complexes for each study area are presented in Table 46. These data show that Scapegoat is similar to Slategoat but both are quite different from Danaher. When the importance of one or more complexes is known, whether it be for a wildlife population, for recreation, watershed management or for timber harvesting, then the complexes can be evaluated in terms of absolute area statistics or comparative percentages. For example, Table 46 shows that 8% of the Scapegoat area is composed of the Xeric Pinus Albicaulis Forest Complex whereas Slategoat and Danaher are represented by 4 and .3% respectively. This complex, an important energy source for grizzly bears, is relatively more abundant in Scapegoat than in the other two areas. When other vegetation complexes are similarly examined for percentages of

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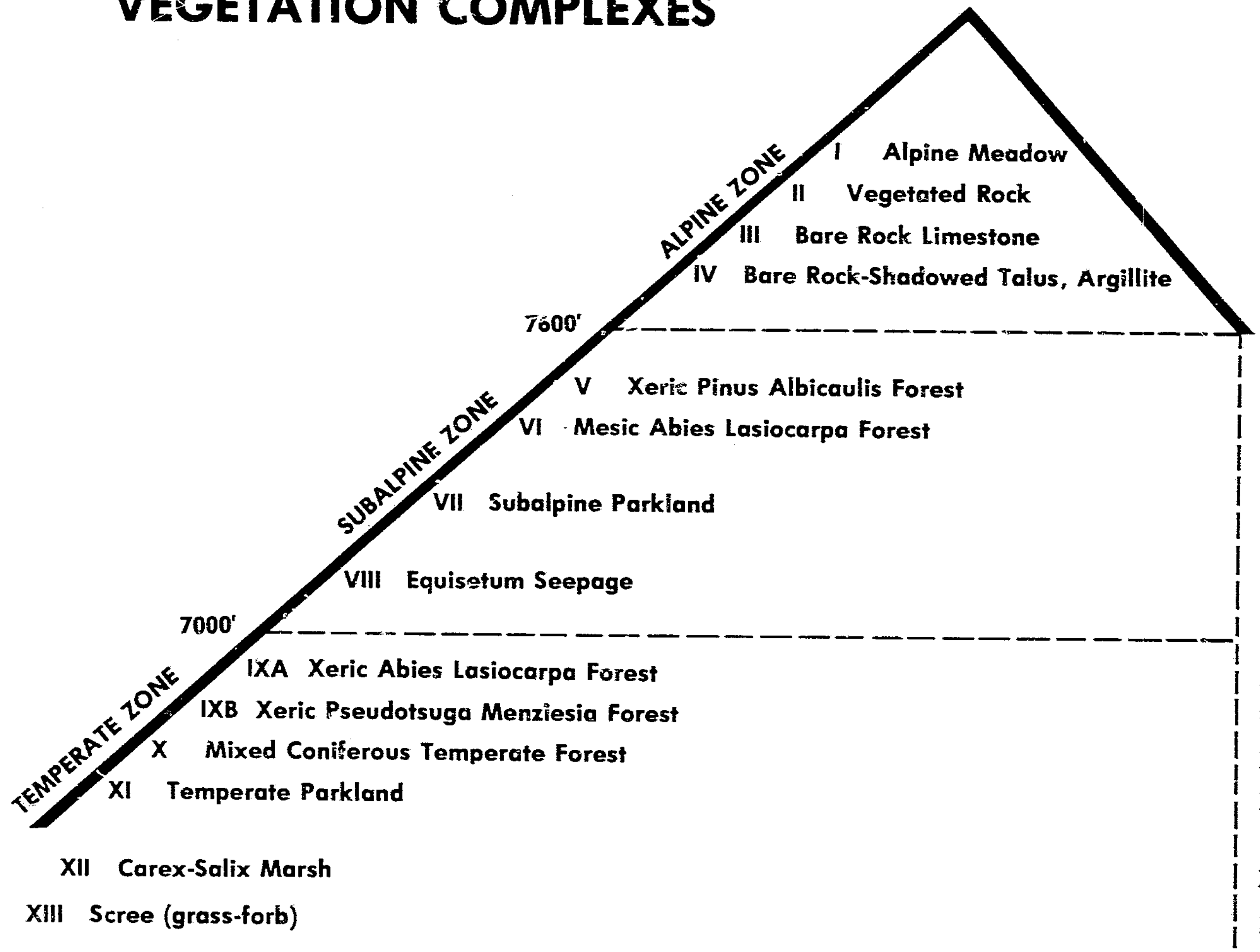
Fig. 51 Diagram of the zonal distribution of computer delineated vegetation complexes.

ZONAL DISTRIBUTION OF VEGETATION COMPLEXES



DIAGNOSTIC VEGETATION OF COMPLEXES

I	Carex-Festuca-Phlox
II	Carex-Festuca-Dryas
III	Lichens
IV	Lichens
V	Abies lasiocarpa (Pinus albicaulis)/Vasc. h.t.
VI	A. lasiocarpa/Luzula hitchcockii Menziesia ferruginea h.t.
VII	Grass-Shrublands & Seral Forests (Burns)-Scree (Carex-Xerophyllum-Festuca)
VIII	Equisetum-Pedicularis groenlandica
IXA	A. lasiocarpa/Xerophyllum tenax-Vagl. h.t.
IXB	Pseudotsuga menziesii/Calamagrostis rubescens
X	A. lasiocarpa/Menziesia ferruginea h.t.
XI	Grass-shrublands & Seral Forests (Burns). Scree (Festuca-Carex)
XII	Carex-Salix-Betula
XIII	Festuca Carex

20-A

bear food plants (Table 45), it becomes possible to compare and to evaluate the three geographic sites as habitat for grizzly bears. Such evaluations will be possible for other geographic areas within the ecosystem when computer extrapolated maps and statistical readouts are available.

A somewhat different approach is to start an evaluation with a specific plant species judged to be important, perhaps critical, to a wildlife species. For example, we know that _Lomatium cous_ is a very important energy source for grizzly bears during June and July. This species is most abundant in the upper subalpine and in the alpine zones, with abundance values of .6% and .7%, respectively. Within the alpine zone it is most abundant in the Vegetated Rock Complex with a value of 1.0%. The acreage of this complex and its distribution throughout the alpine zone are shown in Table 46 and Fig. 28. Any threat to this component of the grizzly bears' environment would directly affect the welfare of the grizzly. When we consider that _L. cous_ is but one of several important grizzly bear food plants found in the Vegetated Rock Complex, (Table 45) then it becomes evident that a threat to this complex in any part of the wilderness ecosystem, whether from natural forces or from human intrusion, must be a factor of great concern.

The system provides the quantitative data to analyze and evaluate the threat.

Similarly, in Section II we learned that *Pinus albicaulis* was extremely important to the grizzly, rating second in importance among a series of food plants. The distribution of this species can be ascertained from Fig. 29 which shows the distribution of the two forest complexes that contain this species. Area percentages for the two complexes are shown in Table 46 with percentages of the various forest habitat types comprising them recorded in Table 14. With information of this kind for the entire ecosystem we could predict the ecological disturbance to grizzly bears, blue grouse (*Dendragapus obscurus*) Clark's nutcrackers (*Nucifraga columbiana*), the pine squirrel or chickaree (*T[illegible]asciurus douglasi*), least chipmunk (*Eutamias minimus*), and other pine-nut-eaters if white bark pine forests were burned, or heavily attacked by the white pine blister rust (*Cronardium ribicolae*), or the western bark beetle (*Dendroctonus monticolae*). In the past, *Pinus albicaulis* has experienced epidemic attacks from these two pests throughout its geographic range. It could conceivably be eliminated as a viable forest species. More attention should be paid to its ecologic role in animal communities and to its susceptibility to decimating

factors. Statistical readouts from computer mapping can provide the data base for an analysis of this critical problem.

The system of computer maps, statistical readouts and supporting data can be applied to the management of a wide range of wilderness species. Habitat can be quantitatively evaluated for any species whose feeding habits have been well documented.

For example, to evaluate the Scapegoat and Slategoat for bighorn sheep (Ovis canadensis) we would first assemble food habits data for specific populations inhabiting the area. Then we would prepare sheep food plant abundance tables and charts similar to those prepared for the grizzly bear (Table 45 and Figs. 48 and 49). These would indicate which vegetation complexes had the highest food abundance ratings for sheep and which of numerous specific food plants were most abundant. From Table 46 we would then determine the area percentages of each complex. This information when converted to food abundance and distribution ratings, would enable us to make a value judgement as to which of the two areas are best suited for bighorns. Other factors such as size and distribution of lambing areas, escape sites, shelters, and the presence or absence of predators are, of course, important considerations. However, the food

resource is basic and thus can serve as the initial rating criterion.

In a similar way the two areas or the entire wilderness ecosystem can be rated and compared. The habitat of elk (Cervus canadensis), mule deer (Odocoileus hemionus), martin (Martes americana) as well as that for rodents such as the Columbian ground squirrel (Spermophilus columbianus), and the hoary marmot (Marmota caligata) can be quantified, evaluated and rated. Birds such as the Franklin's grouse (Canachites franklini) and Stellar Jay (Cyanocitta stelleri) to mention only a few, can be studied and managed in relation to their habitat requirements.

Predators such as the gray wolf (Canis lupus), the cougar (Felis concolor), and wolverine (Gulo gulo) are dependent on prey species that, in turn, are dependent on vegetation. When the food habits of the wolf, cougar, and wolverine become well documented in the Scapegoat southern Bob Marshall region, the entire ecosystem or the habitat in any portion of it can be quantitatively evaluated for these predatory species using the LANDSAT multi-spectral imagery analysis system to map and quantify the vegetation.

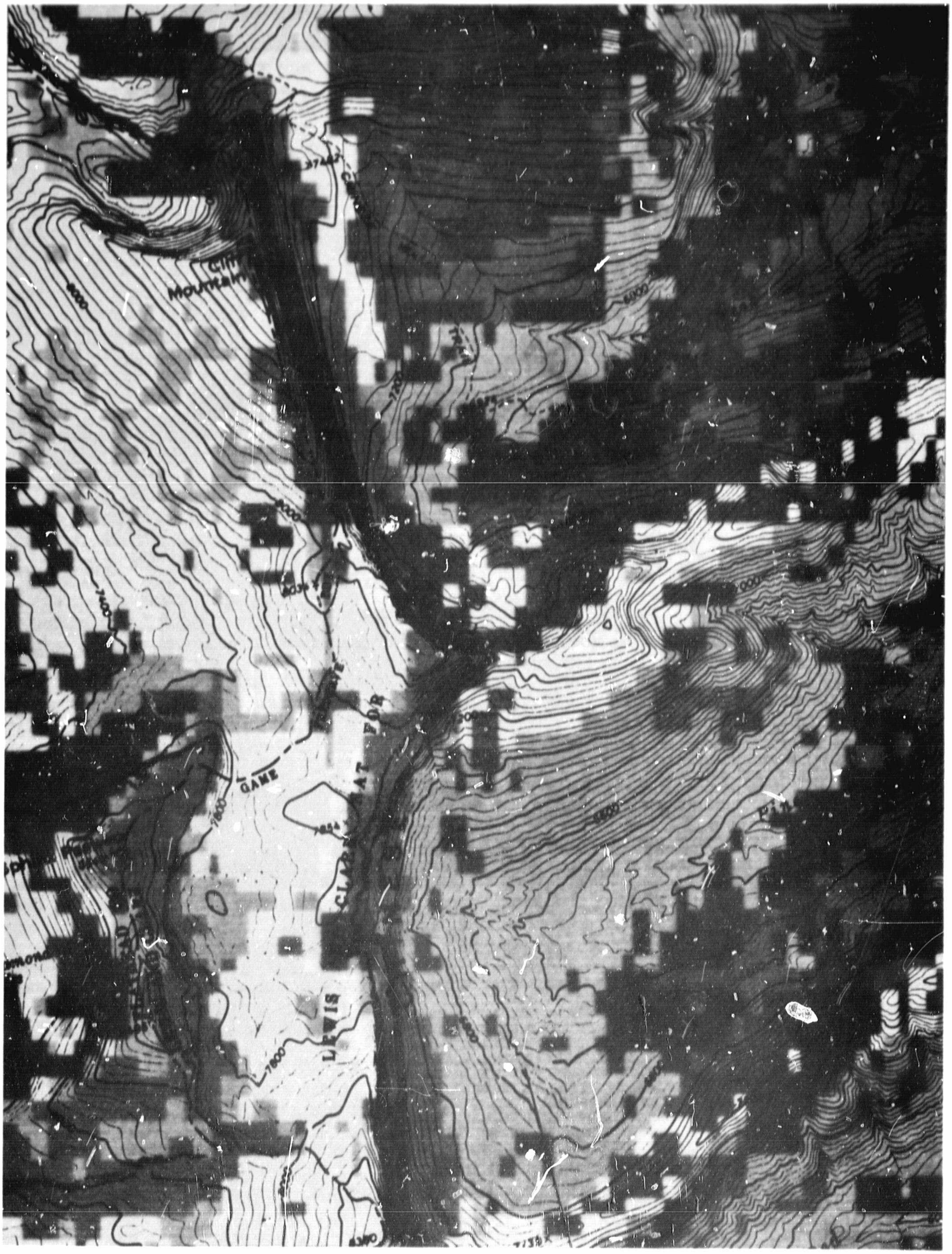
Numerous other advantages over conventional ground or aerial mapping are evident. One of the most obvious is that

computerized color coded maps and statistical readouts can be obtained for all or any portion of the geographic area of interest. For example, once the system is in full operation for a specified "ecosystem," a resource manager can request a map of the entire ecosystem (say 2,000 square miles 5180 km^2) with statistical readouts for each vegetation complex. He can obtain various scaled color coded maps up to 3 inches to the mile (1:21120) of small specific areas of interest also with statistical readouts (Fig. 52). These define the resource base, providing the fundamental inventory information essential for long term, integrated resource planning.

The mapping system with its array of statistical support provides numerous interpretive possibilities. When applied to large multiple-use forests or grazing lands, it will be possible to estimate timber or forage production for vast areas by applying yield statistics. The probable effects of road construction, controlled burning, timber harvesting, and grazing intensity can be estimated and computer-extrapolated in a similar fashion.

Because the system quantifies habitat parameters, the size and distribution of animal populations and their seasonal use of habitat can be computer-predicted. In the case of the grizzly bear for example, a census of animals in the alpine zone

Fig. 52 Three-inches-to-the-mile (1:21120) enlargement of a portion of the Slategoat map extrapolated from the signatures derived for the primary Scapegoat area. Similar maps in half tone or in color can be made to specified sizes and scales with computer summaries of a wide range of statistical data pertaining specifically to the designated area of interest. This can be accomplished rapidly at relatively little expense. The maps can be continuously updated from recent MSS imagery and their usefulness periodically improved from a digitized data base.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during late June and throughout July could be computer-extrapolated for the entire wilderness ecosystem. Grizzlies are more easily observed and counted in this zone than elsewhere. Most members of a population visit the alpine zone during this time frame. Data on the number, sex, and age of bears observed and the vegetation complexs used can be translated into a density expression of so many animals per acre or per square mile of habitat. A relatively small number of sample census sites could provide data that when computer-extrapolated by vegetation complex would yield a sufficiently accurate ecosystem density estimate for most management purposes. Application of data from radio-instrumented bears could provide even more precise data.

The computer-mapping system I have described can precisely quantify grizzly bear habitat throughout an entire ecosystem. With appropriate input it can also provide estimates of grizzly bear numbers or bear density throughout the same vast area. The accuracy of such ecosystem estimates is dependent on sampling skill and intensity. The more accurate the sampling the more precise the computer-extrapolated results.

DISCUSSION

The information presented in this and in preceeding Sections (I and II) conclusively prove that vegetation can be mapped with detail and with accuracy using multispectral imagery and computer assistance. The vegetation sampling must be done for the area of interest, by employing land/vegetation classifications based on ecological principles. The results can then be converted to a computerized classification consistent with spectral values. Normally this will involve a rearrangement of vegetation classification units into larger vegetation classification complexes. The degree of botanical detail describing any given complex is dependent on sampling intensity. The greater the botanical detail the greater the value of the resulting eco-spectral classification system.

In geographic areas where multispectral imagery is available but vegetation classifications are not or are incomplete, mapping with LANDSAT imagery will be severly constricted until ecological classifications of vegetation are developed. I wish to re-emphasize that the computer-modeled multispectral imagery mapping of vegetation is essentially the conversion of an ecological classification to an eco-spectral one. The value of the eco-spectral classification

is that, within prescribed ecological limits, it can be computer-extrapolated for relatively large geographic areas minimizing mapping time and costs and maximizing resource information.

A data base of soil, geologic, and hydrologic maps can be digitized into the computer system. Once these are introduced, coordinate conversion and scale changes can be made; then merged with other maps, including the multispectral imagery ones, and displayed with all data at a common scale. By means of the polygon and grid overlay techniques the "multilayered" data can be computer analyzed to determine combinations of data and their frequency of occurrence.

Data can be computer displayed for an entire ecosystem or retrieved from the same data base for any one of the vegetation complexes or a combination of them. They can be analyzed and evaluated in terms of the entire data base with emphasis on specific areas of interest.

Our National Wilderness Preservation System is, in itself, a data bank for the future. The pristine areas that comprise the system serve as ecologic norms against which we can compare nation-wide man-induced environmental changes.

As a nation we have emphasized and extolled the abstract qualities of wilderness,--space, solitude, wildness, diversity,

beauty and the aesthetic and spiritual bonds between man and primal nature. These values are essential to man's well-being, perhaps ultimately to his survival. But also imperative is a better understanding of the biological complexities and natural order governing undisturbed nature. Such understanding is dependent on concrete quantitative data. Only with a holistic comprehension of the complexity, diversity and oneness of wilderness can we hope to preserve it in perpetuity from the consuming forces of a resource-exploitive society. Moreover, only by understanding the ecology of wilderness can we protect non-wilderness as a viable habitat for man. Structured, digitized computer compatible data used in conjunction with multispectral image analysis constitutes a remarkably versatile and efficient system for planning and for understanding the wilderness resources.

C-4

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APPENDIX

APPENDIX

Table 1 Occurrence of ecological land units, landtypes and forest habitat types, in the vegetation complexes of the primary and secondary study areas as determined by the grid square technique.

ALPINE CLIMATIC ZONE (>7600') - SCAPEGOAT AND SLATEGOAT

Vegetation Complex (Class)	Percent Area	Description and Composition by Ecological Land Units	Occurrence* Scapegoat (Primary)	Occurrence* Slategoat (Secondary)	Total
Complex I: ALPINE MEADOW	7.7	Climax Vegetation: Carex spp.			
		Alpine Meadow Krummholz**	63	167	230
		Alpine Meadow	22	29	51
		Vegetated Talus	3	4	7
		Total	88	200	288
Complex II: VEGETATED ROCK	5.0	Climax Vegetation: Dryas octopetala			
		Mountain Massif and Glacial Cirque Basin	70	96	166
		Semi-vegetated Talus	33	35	68
		Fellfield	21	21	42
		Bare Talus	16	6	22
		Alpine Meadow Krummholz		9	9
		Parent Rock-Limestone	8		8
		Total	148	167	315
Complex III: BARE ROCK	6.4	Climax Vegetation: Lichens			
		Parent Rock-Limestone	30	64	94
		Bare Talus	22	52	74
		Semi-vegetated Talus	8	5	13
		Snowfield and Snowfield Sinks	5		5
		Fellfield	2		2
		Total	67	121	188
Complex IV: BARE ROCK	5.0	Climax Vegetation: Lichens			
		Bare Talus in shadow	22	19	41
		Parent Rock-Argillite	9	28	37
		Total	31	47	78

*Occurrence of vegetation complexes were calculated employing the grid overlay with the third generation computer map (see METHODS).
**Alpine Meadow Krummholz includes Slab Rock Steps Krummholz and Slab Rock Krummholz.

Table 1 Continued.

SUBALPINE CLIMATIC ZONE (7600'-7000') - SCAPEGOAT AND SLATEGOAT

Vegetation Complex (Class)	Percent Area	Description and Composition by Forest Habitat Types or by Ecological Landtypes	Occurrence Scapegoat (Primary)	Occurrence Slategoat (Secondary)	Total
Complex V: XERIC PINUS ALBICAULIS FOREST; predom. E, SE, S, SW exposures; light canopy cover (15-35%).	6.8	Climax Vegetation: Abies lasiocarpa			
		831 Abies lasiocarpa/Luzula hitchcockii-Vaccinium scoparium	134	120	254
		820 Abies lasiocarpa(Pinus albicaulis)/Vaccinium scoparium	70	40	110
		850 Pinus albicaulis-Abies lasiocarpa	47	12	59
		010 SCREE	23	4	27
		832 Abies lasiocarpa/Luzula hitchcockii-Menziesia ferruginea	15		15
		692 Abies lasiocarpa/Xerophyllum tenax-Vaccinium scoparium	14		14
		691 Abies lasiocarpa/Xerophyllum tenax-Vaccinium globulare	9		9
		860 Larix lyallii-Abies lasiocarpa	9		9
		Total	321	176	497
Complex VI: MESIC ABIES LASIOCARPA/PINUS ALBICAULIS FOREST; predom. NE, N, NW, W exposures; moderate to heavy canopy cover. (35%)	16.4	831 Abies lasiocarpa/Luzula hitchcockii-Vaccinium scoparium	177	64	241
		832 Abies lasiocarpa/Luzula hitchcockii-Menziesia ferruginea	90	8	98
		820 Abies lasiocarpa(Pinus albicaulis)/Vaccinium scoparium	59	52	111
		670 Abies lasiocarpa/Menziesia ferruginea	53		53
		850 Pinus albicaulis-Abies lasiocarpa	24	12	36
		860 Larix lyallii-Abies lasiocarpa	22	8	30
		691 Abies lasiocarpa/Xerophyllum tenax-Vaccinium globulare	22		22
		690 Abies lasiocarpa/Xerophyllum tenax	14		14
		692 Abies lasiocarpa/Xerophyllum tenax-Vaccinium scoparium	12		12
		650 Abies lasiocarpa/Calamagrostis canadensis	3		3
		Total	476	144	620

Table 1 Continued.

Vegetation Complex (Class)	Percent Area	Description and Composition by Forest Habitat Types or by Ecological Landtypes	Occurrence: Scapegoat (Primary)	Occurrence: Slategoat (Secondary)	Total
Complex XIII: SCREE (grass-shrub)	3.3	Festuca idahoensis, Carex spp.	-	-	-
Complex VII: SUBALPINE PARKLAND	10.6	Climax Vegetation: Festuca spp., Abies lasiocarpa			
		SCREE	94	16	110
		Xeric to mesic seral forest stages (burns)	72	116	188
		Xeric subalpine grass-shrublands	57	60	117
		Total	223	192	415
Complex VIII: EQUISETUM SEEPAGE	.4	Equisetum arvense, Pedicularis groenlandica	0	2	2

Table 1 Continued.

TEMPERATE CLIMATIC ZONE (<7000') - SCAPEGOAT AND DANAHER

Vegetation Complex (Class)	Percent Area	Description and Composition by Forest Habitat Types or by Ecological Landtypes	Occurrence Scapegoat (Primary)	Occurrence Slategoat (Secondary)	Total
Subcomplex IXA: XERIC ABIES LASIOCARPA FOREST; predom. E, SE, S SW exposures; light canopy cover (15-35%).	5.4	Climax Vegetation: Abies lasiocarpa			
		691 Abies lasiocarpa/Xerophyllum tenax-Vaccinium globulare	75	44	119
		692 Abies lasiocarpa/Xerophyllum tenax-Vaccinium scoparium	67	20	87
		820 Abies lasiocarpa (Pinus albicaulis)/Vaccinium scoparium	12		12
		670 Abies lasiocarpa/Menziesia ferruginea	8		8
		010 SCREE	7	4	11
		750 Abies lasiocarpa/Calamagrostis rubescens	6		6
		650 Abies lasiocarpa/Calamagrostis canadensis	2	4	6
		630 Abies lasiocarpa/Galium triflorum		4	4
		Total	177	76	253
Subcomplex IXB: XERIC PSEUDOTSUGA MENZIESII FOREST; predom. E, SE, S, SW exposures; light canopy cover (15-35%).		Climax Vegetation: Pseudotsuga menziesii			
		320 Pseudotsuga menziesii/Calamagrostis rubescens	18		
		360 Pseudotsuga menziesii/Juniperus communis	13		
		010 SCREE	4	8	12
		321 Pseudotsuga menziesii/Calamagrostis rubescens-Agropyron spicatum		16	16
		270 Pseudotsuga menziesii/Xerophyllum tenax		8	8
		321 Pseudotsuga menziesii/Calamagrostis rubescens-Agropyron spicatum		80	80
		Total	35	112	147
Complex X: MIXED CONIFEROUS FOREST; predom. NE, N, NW, W exposures; heavy canopy cover (35%).		Climax Vegetation: Abies lasiocarpa or Pseudotsuga menziesii			
		670 Abies lasiocarpa/Menziesia ferruginea	278	64	342
		691 Abies lasiocarpa/Xerophyllum tenax-Vaccinium globulare	179	168	347
		692 Abies lasiocarpa/Xerophyllum tenax-Vaccinium scoparium	106	20	126

Table 1 Continued.

Vegetation Complex (Class)	Percent Area	Description and Composition by Forest Habitat Types or by Ecological Landtypes	Occurrence Scapegoat (Primary)	Occurrence Slategoat (Secondary)	Total
Complex X: Continued.		750 Abies lasiocarpa/Calamagrostis rubescens	27		
		690 Abies lasiocarpa/Xerophyllum tenax	18	40	58
		820 Abies lasiocarpa(Pinus albicaulis)/ Vaccinium scoparium	14		14
		650 Abies lasiocarpa/Calamagrostis canadensis	11		11
		780 Abies lasiocarpa/Arnica cordifolia	8		8
		360 Pseudotsuga menziesii/Juniperus communis	7		7
		320 Pseudotsuga menziesii/Calamagrostis rubescens	7	7	
		660 Abies lasiocapra/Linnaea borealis		56	56
		323 Pseudotsuga menziesii/Calamagrostis rubescens-Calamagrostis rubescens		88	88
		730 Abies lasiocarpa/Vaccinium scoparium		28	28
		270 Pseudotsuga menziesii/Xerophyllum tenax		32	32
		410 Picea spp./Egar		28	28
		640 Abies lasiocarpa/Vaccinium caespitosum		24	24
		930 Pinus contorta/Linnaea borealis		16	16
		920 Pinus contorta/Vaccinium caespitosum		12	12
		321 Pseudotsuga menziesii/Calamagrostis rubescens-Agropyron spicatum		8	8
		630 Abies lasiocarpa/Galium triflorum		8	8
		322 Pseudotsuga menziesii/Calamagrostis rubescens-Arctostaphylos uva-ursi		4	4
		450 Picea spp./Vaccinium caespitosum		4	4
		312 Pseudotsuga menziesii/Symphoricarpos albus-Calamagrostis rubescens		4	4
		642 Abies lasiocarpa/Vaccinium caespitosum-Calamagrostis canadensis		4	4
		Total	655	608	1263

Table 1 Continued.

Vegetation Complex (Class)	Percent Area	Description and Composition by Forest Habitat Types or by Ecological Landtypes	Occurrence Scapegoat (Primary)	Occurrence Slategoat (Secondary)	Total
Complex XI: TEMPERATE PARKLAND	5.2	Climax Vegetation: *Festuca spp., Abies lasiocarpa, Picea spp., Pseudotsuga menziesii, Pinus contorta*			
		Seral forest stages (burns	57	0	57
		SCREE	26	16	42
		Xeric grass-shrublands	24	72	96
		Total	107	88	195
Complex XII: CAREX-SALIX MARSH	.9	Carex spp., Betual glandulosa, Salix spp.		37	37